CELO-NAVIGATION

DUTTON

Celo-Navigation

Commander Benjamin Dutton, U.S.N.

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CELO-NAVIGATION

PREPARED FOR USE AT THE U. S. NAVAL ACADEMY

By

Commander Benjamin Dutton, U. S. Navy

FOREWORD.

Beginning with the issue for 1925, the data of the Nautical Almanac is to be tabulated for civil time instead of astronomical time. The change in the Nautical Almanac having made necessary a new text on Celo-Navigation, this pamphlet has been prepared by Commander Benjamin Dutton, U. S. Navy. Various officers of the Department of Navigation have assisted by criticizing the text and by preparing and checking the problems. The text is not complete, as it is intended to replace only those parts of Navigation, 1922, which have been rendered obsolete by the change in the Nautical Almanac.

22 August, 1924.

CHAPTER I.

TIME.

1. Time, for general use, is measured by the apparent movement of an imaginary body called the mean sun. This is called mean time, and is used as a measure of duration. The navigator has an additional use for time, that of determining the position of the celestial bodies relative to his meridian. For this purpose he requires two other kinds of time. For determining the position of the true sun he requires a time based upon the apparent movement of that body. This is apparent time. For other celestial bodies he requires a time measured by the apparent movement of the stars. This is sidereal time.

The apparent movements of the celestial bodies are caused by the real movement of the earth. It is the purpose of the following discussion to show how the movement of the earth causes the mean sun, the true sun, and the stars to appear to move at different rates and to make clear the uses and the relations of the different kinds of time based upon those different rates of movement.

The earth has two distinct motions:

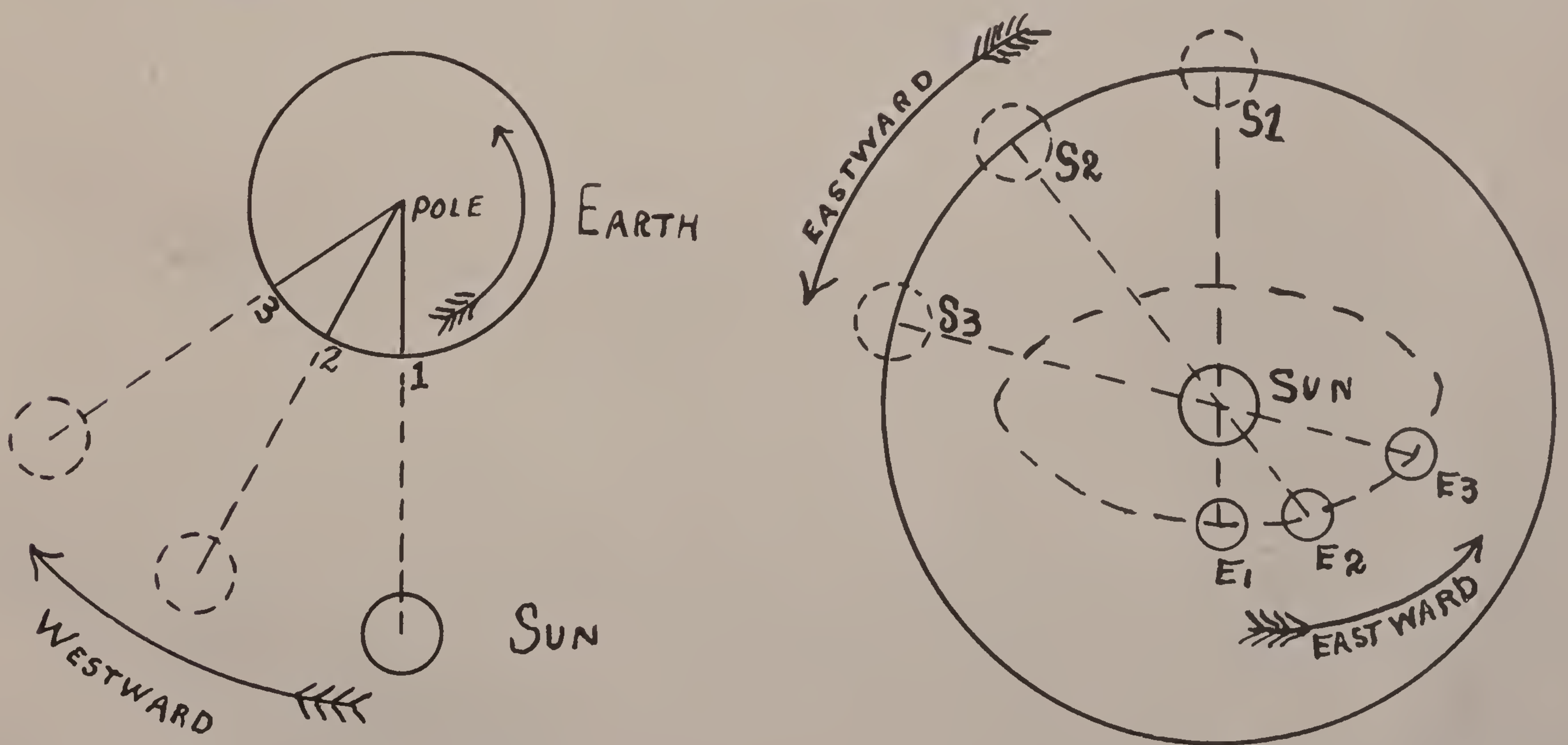
First, a perfectly uniform rotation to the eastward about its axis. There are 366.24+ rotations in the period of time called a solar year. Each of these rotations takes place in exactly the same period of time and at a uniform rate.

Second, one yearly revolution to the eastward about the sun, in the plane of the ecliptic. Each of these revolutions is completed in the same period of time, but since the orbit of the earth about the sun is an ellipse, and since the earth moves at a varying speed in that orbit, the angular rate of the movement is constantly varying throughout the year.

The effect of these two motions of the earth in causing the apparent motion of the sun is as follows: Although both the motions of rotation and revolution are in the same direction, to the eastward, the apparent revolutions of the sun which they cause, are in opposite directions. Thus, the rotation to the eastward will cause any celestial body to appear to revolve to the westward, while the revolution will cause the sun, which is within the orbit, to appear to revolve to the eastward. See Figure 1.

FIGURE 1.

EFFECT OF ROTATION. EFFECT OF REVOLUTION.



The sun will successively transit meridians 1, 2, and 3, or apparently move to westward.

As the earth successively occupies positions E1, E2, E3, the sun will be projected on the ecliptic in positions S1, S2, S3, apparently moving to the eastward.

The sun's apparent yearly motion therefore has two components, which are, first, 366.24+ revolutions to the westward at a uniform rate, caused by the earth's rotation, and second, one yearly revolution to the eastward at a varying rate, caused by the earth's revolution. The net result is that the sun makes 365.24+ yearly revolutions to the westward, at a varying rate.

Due to the inclination of the planes of the ecliptic and the equinoctial, the sun's variable motion in the ecliptic becomes more variable when projected on the equinoctial, where hour angles are measured. It is evident that the rate of change of the sun's hour angle is not uniform.

As the sun's apparent motion causes our periods of darkness and light, as well as the cycles of the seasons, it is the natural measure of time. Since, however, as explained above, its rate of change of hour angle is not uniform, it does not provide a practical measure because the units of time as determined by its motion are of constantly varying lengths. To obviate this disadvantage, and to retain the advantage of a time measurement based upon the motion of the sun, an imaginary sun called the mean sun is used.

2. The Mean Sun. This is an imaginary sun which moves to the eastward in the equinoctial at a uniform rate equal to the average rate of the true sun in the ecliptic. (See Figure 1.) Due to the earth's revolution about the sun, the latter appears to move in the ecliptic at an *average* daily rate of 3^m–$56^s.6$. Therefore the mean sun is supposed to move *uniformly* at that rate in the equinoctial, *i. e.*, to increase its right ascension 3^m–$56^s.6$ every day. Under this assumption both components of the apparent motion of the mean sun are uniform. Its total motion is therefore uniform, and the units of time as measured by its movement are of unvarying length.

3. Mean Time. Time as measured by the apparent motion of the mean sun is called mean time. In mean time the mean solar day is the interval of time required for the mean sun to make one apparent revolution about the earth. Formerly navigators considered the day as beginning at the instant the sun crossed the upper branch of the meridian, *i. e.*, at noon. Mean time, with the beginning of the day, at that instant, is called astronomical time. Navigators now use the instant of transit of the sun across the lower branch of the meridian (midnight) as the beginning of the day. Time so reckoned, *i. e.*, by the apparent motion of the mean sun with the instant of lower transit as the origin of the day, is called civil mean time, or more commonly, civil time. In general practice the twenty-four hours which constitute the day are divided into two equal periods of twelve hours each. The period next succeeding the lower transit is indicated by writing A.M. after the hours, and the period next succeeding upper transit indicated by writing P.M. after the hours. For navigational purposes the hours are numbered from zero at lower transit to twenty-four hours at the next lower transit, and the suffixes a.m. and p.m. are omitted.

From this point on, the term civil time will refer to civil time with the hours numbered from 0 to 24, and times given as civil times will be so numbered.

CIVIL TIME AND THE HOUR ANGLE OF THE MEAN SUN.

4. As the civil day begins at the instant of the lower transit of the mean sun the civil time at any place at any instant is equal to the hour angle of the mean sun as measured from the lower branch of the meridian at that instant.

Later on, in dealing with sidereal time, it will be found convenient to restate the above as follows: Hour angles are measured from the upper branch of the meridian. Therefore, at the beginning of the civil day, at lower transit, the hour angle of the mean sun is twelve hours. From this instant, as the sun advances to the westward, the hour angle of the sun and the civil time increase in unison, so that the civil time is always equal to the hour angle of the mean sun plus twelve hours, dropping twenty-four hours if the sum exceeds that amount.

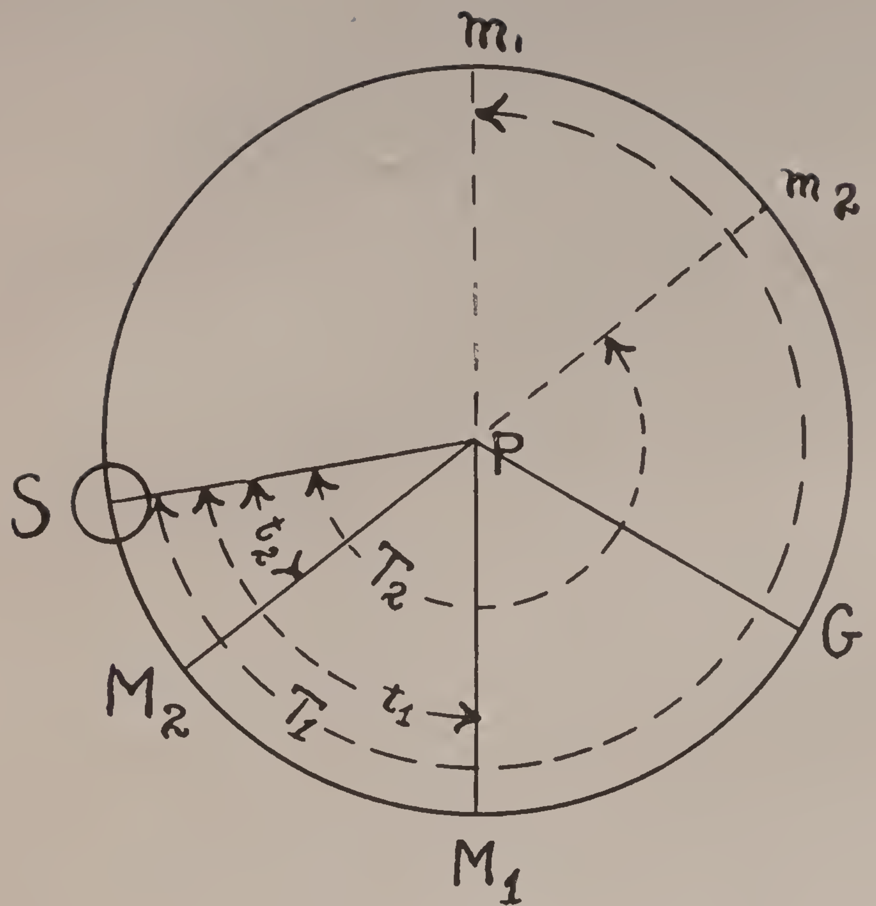


Fig. 2.

Let S be the mean sun.

Let PG, be the meridian of Greenwich, and PM_1 and PM_2 the meridians of two other places, Pm_1 and Pm_2 being the lower branches. Then GM_1 and GM_2 are the longitudes of PM_1 and PM_2. Call these λ1 and λ2.

M_1S and M_2S are the hour angles of the sun from M_1 and M_2. Call these t_1 and t_2.

Then T_1 and T_2 (see figure), will be the civil times for the meridians PM_1 and PM_2. By inspection

$$T_1 = t_1 + 12$$
$$\text{and} \quad T_2 = t_2 + 12.$$

(1) Hence the local civil times at any two places differ as the hour angles of the mean sun as measured from those places.

Now, by inspection, $\lambda_2 - \lambda_1 = M_1\,M_2$

$$\text{and } t_1 - t_2 = M_1\,M_2$$

$\therefore\ \lambda_2 - \lambda_1 = t_1 - t_2$

(2) Or the hour angles of the sun from two places differ as the longitudes of those places.

Pm_1 and Pm_2 being the lower branches of the meridians of PM_1 and PM_2, the times at M_1 and M_2 are T_1 and T_2

$T_1 - T_2 = m_1\,m_2 = M_1\,M_2 = \lambda_2 - \lambda_1$

(3) ∴ At any two places the local civil times differ as the longitudes of those places.

(4) Hour angles are measured to the westward, therefore of two meridians, that one which is farthest to the east will have the largest hour angle and the later time.

(5) Combining (3) and (4)—The local times at any two places differ as the longitudes of those places, and the place farthest east has the later time.

CONVERSION OF ARC AND TIME UNITS.

5. As longitudes are expressed in units of arc, and hour angles and time are expressed into time units, it becomes necessary to convert arc units into time units before applying the above rules. The relationship between the two sets of units is based upon the fact that the sun completes its apparent revolution of 360° of longitude in 24 hours, and therefore 1 hour of time = 15° of arc. Also, 1 minute of time = 15′ of arc, and 1 second of time = 15″ of arc. Therefore a given number of degrees, minutes, or seconds of arc may be converted to hours, minutes, or seconds of time by dividing by 15.

Since 15° of arc equal 1 hour, or sixty minutes of time, 1° of arc equals 4 minutes of time. Therefore if a given number of degrees of arc is not exactly divisible by 15 the conversion to time may be completed by simply multiplying the remainder by four and denoting the product as minutes of time, thus:—

Reduce 43° to time units.

$$\frac{43}{15} = 2 \text{ with remainder } 13 = 2 \text{ hours and } 52 \text{ minutes.}$$

The same reasoning will hold for reducing minutes of arc to minutes of time.

Thus, reduce 43′ to time.

$$\frac{43}{15} = 2 \text{ and } 13 \text{ over} = 2 \text{ minutes and } 52 \text{ seconds.}$$

Now reduce 43°–43′ to time units.

$$\frac{43^\circ}{15} = 2 \text{ with remainder } 13 = 2 \text{ hours } 52 \text{ minutes.}$$

$$\frac{43'}{15} = 2 \text{ with remainder } 13 = \qquad 2 \text{ minutes } 52 \text{ seconds.}$$

$$43^\circ\text{—}43' \qquad = 2 \text{ hours } 54 \text{ minutes } 52 \text{ seconds.}$$

A remainder left over when dividing seconds of arc by 15 must be carried as a fraction of a second of time or preferably reduced to a decimal. (The nearest tenth is sufficiently accurate in navigation.)

In practice the form for work is more convenient as shown below:

Reduce 43°–43′–43″ to time units.

$$\begin{array}{l} 15/43^\circ\text{–}43'\text{–}43'' \\ \hline 2\text{–}52 \\ \quad 2\text{–}52 \\ \qquad 2\tfrac{13}{15} \\ \hline 2^h\text{–}54^m\text{–}54^s.9 \end{array}$$

Problems. Convert into time:

29°–43′–30″.
155°–13′–43″.
177°–15′–30″.

Answers:

1^h–$58^m 54^s$.
10^h–20^m–54.87^s.
11^h–49^m–02^s.

CONVERTING TIME INTO ARC.

Since 1 hour of time = 15° of arc, a given number of hours may be converted to degrees of arc by simply multiplying by 15. Similarly a given number of minutes of time may be converted into minutes of arc by multiplying by 15, but, as the product will usually exceed 60′, it must be further reduced to degrees and minutes by dividing by 60. Thus: 10 minutes of time = 10×15 minutes arc = 150′ = 2°–30′. The same result is obtained more directly by remembering that any number, as x, of minutes of time is equal to $\frac{x}{60}$ hours of time. Converting hours of time to degrees of arc as before by multiplying by 15, we have $\frac{x}{60}\times 15 = \frac{15x^\circ}{60} = \frac{x}{4}$ degrees. Thus 23 minutes of time $= \frac{23}{4}$ degrees of arc, = 5°–45′.

Convert 2^h–30^m–27^s of time to arc.

$$2^h = \qquad 30^\circ$$

$$30^m = \frac{30^\circ}{4} = \; 7^\circ\text{–}30'$$

$$27^s = \frac{27'}{4} = \qquad 6'\text{–}45''$$

$$37^\circ\text{–}36'\text{–}45''$$

Or the work may be done more conveniently in the following form:

$$\begin{array}{l} 2^h\text{–}30^m\text{–}27^s \\ \hline 30^\circ \\ \;\; 7^\circ\text{–}30' \\ \qquad 6'\text{–}45'' \\ \hline 37^\circ\text{–}36'\text{–}45'' \end{array}$$

PROBLEMS. Convert into arc:	ANSWERS:
$6^h–15^m–32^s$	93°–53′–00″
$10^h–53^m–45^s$	163°–26′–15″
$11^h–35^m–15^s$	173°–48′–45″

RELATIONS OF LOCAL TIMES AND DATES AT TWO PLACES.

6. Knowing the longitude of a place and the local time at that place, the time at another place of known longitude may be found from (5), by first converting the difference in longitude between the two places to time units and applying it to the known time at the first place, adding if the second place is east of the first, and subtracting if it is west.

PROBLEM: At a place, A, whose longitude is 75° W., the time is 17^h. Find the time at the same instant at Greenwich, and at places whose longitudes are 150° W., and 30° E. Ans. 22^h, 12^h, 0^h.

When the sum of the time at one place plus the difference in longitude between the two places is greater than twenty-four, twenty-four hours must be dropped from the time and one added to the date of the second place.

PROBLEM: Place A, longitude 47°–23′ W., times $7^h–10^m$, April 23rd; $22^h–13^m–27^s$, April 23rd. Find the corresponding times in a place whose longitude is 47°–23′ E. Ans. $13^h–29^m–04^s$, April 23rd; $4^h–32^m–31^s$, April 24th.

When the second place is west of the place whose time is known, and the dfference in longitude is greater than the known time, it is necessary to add 24 hours to the time and subtract one from the date before applying the difference in longitude. Thus, suppose at a place in 50°–27′ west longitude, the time is $1^h–43^m$, April 23rd, and it is desired to find the time at a place whose longitude is 158°–18′ west. The difference in longitude is $107°–51' = 7^h–11^m–24^s$. The time at the first place is $1^h–43^m$, April 23rd, or $25^h–43^m$, April 22nd. Subtracting the longitude from the latter, the time at the second place is $18^h–31^m–36^s$, April 22nd.

PROBLEMS: The longitudes of certain places and the times at those places are given in the first and second columns below. Find the corresponding times and dates at places whose longitude appears in the third column.

1.	120°–13′–00″ W.	$10^h–51^m–00^s$, Feb. 1	90°–13′ W.
2.	" " "	" " " " "	90°–13′ E.
3.	" " "	" " " " "	44°–47′ E.
4.	" " "	" " " " "	89°- 47′ E.
5.	75°–13′–00″ W.	$1^h–03^m–00^s$, Sept. 21	30°–00′ W.
6.	" " "	" " " " "	105°–00′ W.
7.	60°- 13′–00″ E.	$16^h–16^m–32^s$. Dec. 31,1924	178°–13′ E.
8.	" " "	" " " " "	160°–00′ E.

ANSWERS:

1. 12–51–00, Feb. 1.	5. 4–03–52, Sept. 21.
2. 0–52–44, Feb. 2.	6. 23–03–52, Sept. 20.
3. 21–51–00, Feb. 1.	7. 0–08–32, Jan. 1, 1925.
4. 0–51–00, Feb. 2.	8. 22–55–40, Dec. 31, 1924.

GREENWICH CIVIL TIME AND DATE.

7. When a navigator takes an observation of a heavenly body for the purpose of determining his position at sea, he obtains only one of the coordinates of that body by observation. This is the altitude. Before he can solve the astronomical triangle to determine his position, he requires certain other data, such as the body's declination, or the right ascension of the mean sun. The Nautical Almanac tabulates these data in such a way that they may be found for any instant of Greenwich civil time. To use this tabulated data the navigator must determine the Greenwich civil time and date corresponding to the instant of his observation. This he does by noting the time of observation by the chronometer which is regulated to keep Greenwich civil time. However, since the chronometer face is graduated from zero to twelve hours, instead of zero to twenty-four, the Greenwich civil time, in which the hours are numbered from 0 to 24, may vary from the chronometer reading by twelve hours.

Of course, the chronometer does not indicate the Greenwich date, which may be different from the navigator's local date by one day. All the chronometer gives the navigator is the Greenwich civil time with a liability of error of exactly 12 hours. But the navigator knows the local date, approximate local civil time, and approximate longitude. With these he determines the Greenwich date and approximate time, and from the latter determines whether it is necessary to add twelve hours to the reading of the chronometer to get the exact Greenwich civil time of the instant of his observation.

EXAMPLES: At about 4:00 p.m., 2 February, a ship's D.R. longitude is 72°–32′ W. The navigator observes the sun, using a watch set to local civil time, and obtains the following time data: W 4–03–27, C-W 4–57–55, chro. fast 2^m–01^s. Find the Greenwich date and civil time. First find the Greenwich date and approximate time, thus:

Local civil time	16–03–27, 2 Feb.	
Long.	4–50–08 (west)	
Gr. approx. civil time	20–53–35, 2 Feb.	Hence 12 hours must be added to the chronometer reading.

Now find the exact Greenwich time, thus:

W.	4–03–27
C-W	4–57–55
Chro. face	9–01–22
Chro. fast	2–01
Chro.	8–59–21 (add 12)
Gr. civil time	20–59–21, 2 Feb.

Or the same results may be obtained by means of a time diagram (Figure 3) which is constructed as follows for the data above:

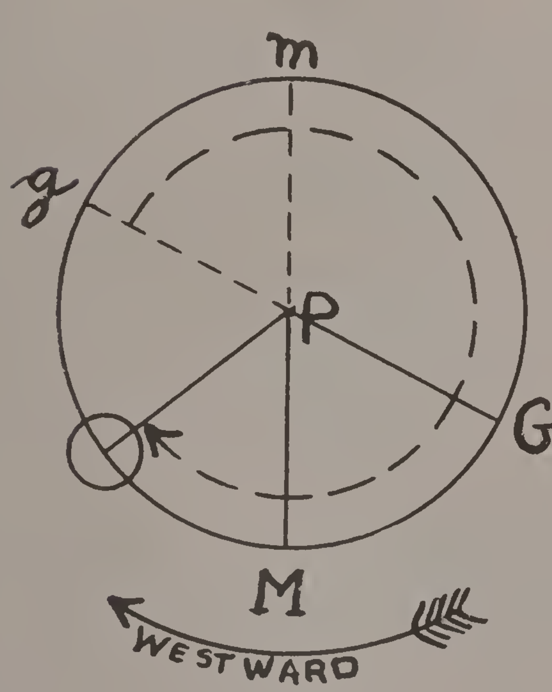
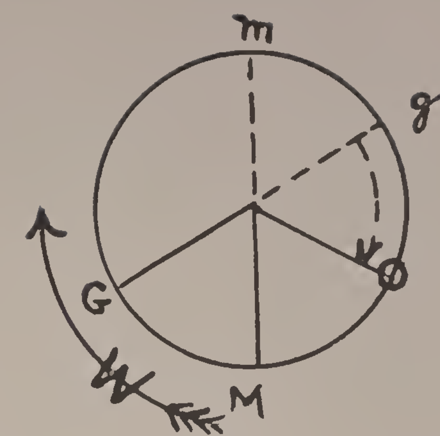


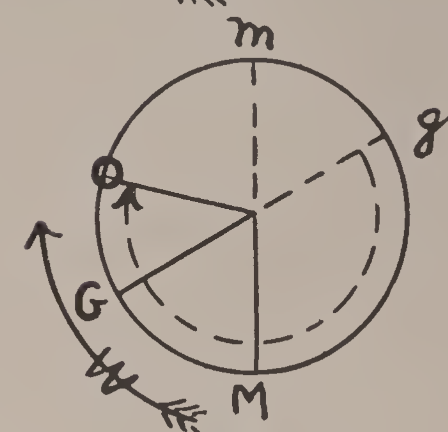
FIG. 3.

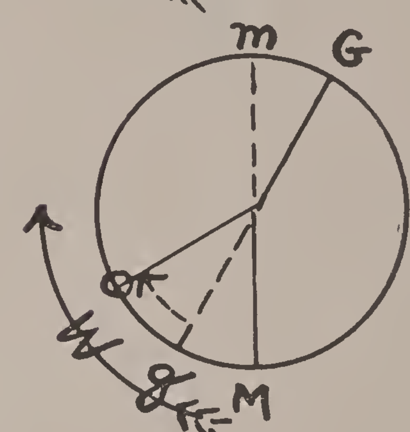
Draw a circle to represent the equinoctial. P, its center, is the pole. Its circumference is considered to be divided into 360° or 24^h, as the case may require. Draw mPM vertically to represent the local meridian, dotting mP, the lower branch. Draw a small circle on the equinoctial to represent the sun. Place this circle at an angular distance from the lower branch of the meridian equal to the local civil time, representing the westward direction as clockwise. Draw the sun's hour circle, ⊙P. Now draw the Greenwich meridian, GPg, so that the local meridian will be to the east or west of it, according as the longitude is east or west, and at a distance equal to the local longitude. Draw the dotted arrow to indicate the hour circle of the sun from the lower branch of the Greenwich meridian. This is the Greenwich civil time. It then will be apparent whether the Greenwich civil time is greater or less than twelve hours. The Greenwich date and the local date will be the same unless the sun is in the smaller sector between the lower meridians. In the latter case, if the sun is to the west of the Greenwich lower meridian, the Greenwich date is one more than the local date, and if to the east, one less. Exactness is not required in these diagrams. They may be drawn free hand.

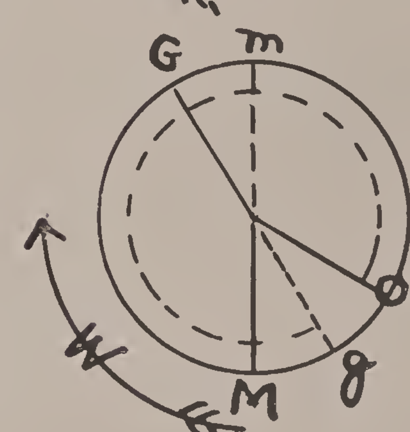
EXAMPLES:

Local civil time	8^h	1 April.		
Longitude	60°	East.	}	Upper Figure.
Greenwich civil time	4^h	1 April.		
Local civil time	19^h	1 April.		
Longitude	60°	East.	}	Second Figure.
Greenwich civil time	15^h	1 April.		
Local civil time	16^h	21 Sept.		
Longitude	150°	West.	}	Third Figure.
Greenwich civil time	2^h	22 Sept.		
Local civil time	8^h	21 Sept.		
Longitude	150°	East.	}	Lower Figure.
Greenwich civil time	22^h	20 Sept.		









PROBLEMS: Given the following data, find the Greenwich civil time and date.

	Watch Time.	C-W.	Chro. Error.	Approximate Longitude.	Date.
1.	6–30–50	7–45–10	2^m–20^s slow	100° W.	Jan. 2, a.m.
2.	10–50–51	7–12–25	1^m–27^s fast	72° E.	May 4, a.m.
3.	4–02–19	4–03–49	3^m–01^s slow	61° W.	Jan. 19, p.m.
4.	5–59–00	8–42–25	0^m–26^s fast	49° E.	May 3, p.m.
5.	6–05–30	9–02–48	1^m–42^s slow	136° W.	Jan. 10, p.m.
6.	5–50–10	1–27–04	1^m–01^s fast	159° E.	Jan. 24, a.m.
7.	3–20–00	10–03–24	2^m–02^s fast	150° W.	May 29, p.m.
8.	11–15–00	1–43–01	1^m–59^s slow	26° W.	Jan. 14, p.m.
9.	6–02–56	3–00–06	2^m–00^s slow	135° E.	May 19, a.m.

ANSWERS:

1. 14–18–20, Jan 2.	4. 14–40–59, May 3.	7. 1–21–22, May 30.
2. 6–01–49, May 4.	5. 3–10–00, Jan. 11.	8. 1–00–00, Jan. 15.
3. 20–09–09, Jan. 19.	6. 19–16–13, Jan. 23.	9. 21–05–02, May 18.

GAIN OR LOSS OF TIME WITH CHANGE OF POSITION.

8. It has been shown that local noon at any meridian is the instant when the sun is on the upper branch of that meridian, that at all places east of that meridian at that instant it is past noon, or time is fast of that of the given meridian; at all places west of that meridian it is not yet noon, or time is slow of that of the given meridian. Hence it is evident that if a navigator travels east, carrying a watch regulated to the time of the meridian departed from, and if he desires to set the watch to the time of a meridian to the eastward, he must set it ahead at the rate of 1 hour for every 15° change of longitude, or 24 hours for every 360°.

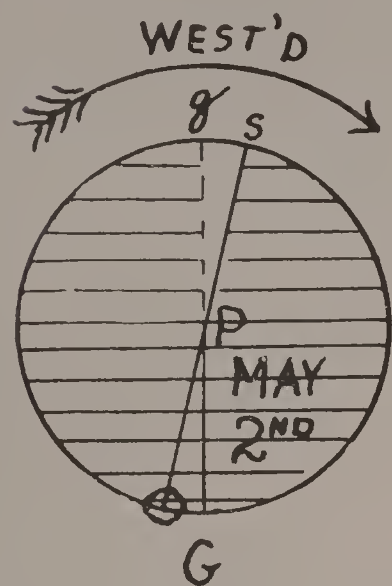
(a)

GREENWICH NOON.

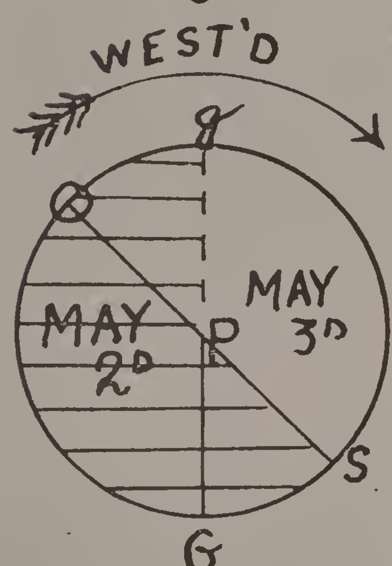
9. The instant of Greenwich noon is one of particular interest to navigators, for it is at this instant, and at this instant only, that the same date prevails throughout the earth. This is shown in Figure (a), in which PG is the meridian of Greenwich, and Pg is the 180th meridian. Assume a date for the figure, say May 2nd. Then the time and date at Greenwich being 12 hours of May 2nd, the date over the entire world is May 2nd, and the time on every 15th meridian will be as shown. Note, however, that on the 180th meridian the time of this instant may be expressed as either 0 hours or 24 hours of May 2nd, according as the longitude is reckoned as west or east. Now 24 hours of May 2nd may be expressed as 0 hours of May 3rd. This is the first instant that the date May 3rd has been in effect anywhere on the earth. Therefore, making a general case, a new date first comes into effect on the earth at the 180th meridian at the instant of Greenwich noon.

CROSSING THE 180TH MERIDIAN.

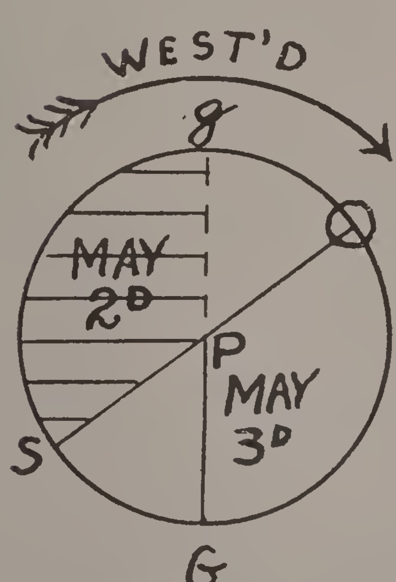
10. The figures that follow are intended to illustrate the advance over the world of the new date which came into effect as explained above. They cover the period of 24 hours next succeeding a Greenwich noon. As before, PG and Pg are the meridians of Greenwich and 180°, ⊙ is the sun, P⊙ the meridian the sun transits at the various instants for which the figures are drawn, and Ps is the lower branch of that meridian. The area in which the date of May 2nd is in effect is shaded, and the unshaded area is that in which the date of May 3rd is in effect.



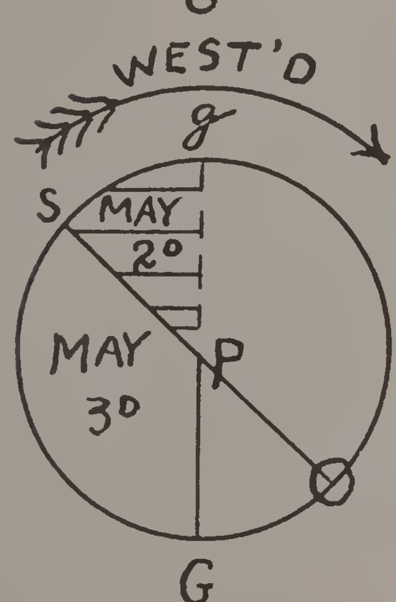
(b)



(c)



(d)



(e)

Figure (b) shows the situation a short time after the instant of 0 hours of May 3rd at the 180th meridian. The sun has crossed the lower branches of all meridians in the sector gPs, and therefore the date of May 3rd is in effect in that sector.

As the sun continues to move to the west, as shown in Figures (c), (d), and (e), it will be seen that the sector gPs constantly increases in size due to the movement of the line Ps, which moves with, but 180° behind, the sun. From an examination of the figures it is apparent that, except at the instant of Greenwich noon, there are always two dates in effect, and that the larger date covers a sector which begins at the 180th meridian and increases to the westward with the movement of the sun. Therefore, if you cross the 180th meridian when traveling westward, you arrive in the sector where the date is one larger than in the sector you just left, and if traveling eastward, you arrive in the sector where the date is one less. Hence the rule: When crossing the 180th meridian sailing westward add one to the date, and if sailing eastward, subtract one from the date, at the same time changing the name of the longitude. The above rule applies to the date used by the navigator. To avoid the inconvenience of changing the name of a day while that day is in effect, the case is handled for ship's time by dropping one day at midnight when the crossing is made westward bound, and repeating one day when eastward bound.

A little consideration will show that, while the date is changed upon crossing the 180th meridian, the time is not changed. The latter is the hour angle of the sun from the lower branch of the meridian and in the infinitesimally small period of time required to cross that imaginary line, the 180th meridian, there is no change in the sun's hour angle.

APPARENT TIME.

11. Time as measured by the apparent motion of the *true* sun is called apparent time. An apparent solar day at any place is the interval of time between two successive transits of the true sun across the lower branch of its meridian, and the time of day is the hour angle of the sun plus twelve hours, dropping twenty-four hours if the sum exceeds twenty-four hours. Apparent noon at a place is the instant of the true sun's transit of the upper branch of the meridian of that place, when its hour angle is zero.

Apparent time at any instant differs in amount from the mean time of the instant by the difference in the hour angles of the mean and apparent suns, or, what is the same thing, by the difference in their right ascensions. This difference is called the equation of time. It has a maximum value of about sixteen minutes and reduces to zero four times during a year. During two periods of the year the mean sun is ahead of the true sun, so that the mean time is greater than the apparent time, and during two periods the reverse is true.

The equation of time is tabulated in the Nautical Almanac (pages 6–29) for every even hour of Greenwich civil time for every day of the year, and may be found for any intermediate instant by interpolation. For convenience in interpolating, the hourly difference in the equation is given for each day. The Nautical Almanac also gives the sign (+ or −) to be used in applying the equation of time to mean time.

TO FIND THE L.A.T. AT A PLACE AT ANY INSTANT.

Find the G.C.T. and date of the instant, and for this G.C.T. and date select the equation of time from the Nautical Almanac. Apply this equation of time to the G.C.T. in accordance with the sign as given. The result will be G.A.T. Apply the longitude of the place to the G.A.T. The result will be L.A.T.

TO CONVERT APPARENT TO MEAN TIME.

12. The equation of time is not tabulated in the Nautical Almanac for apparent time, so that exact conversion of apparent to mean time is not readily accomplished. However, the results will be close enough for most purposes if the equation is selected from the Nautical Almanac with the apparent time as though the latter were mean time, and applied to the apparent time *with the sign reversed.* If a closer approximation is desirable, the equation of time may be selected for the mean time instant as found above, and this second equation of time applied to the apparent time.

If the apparent sun is substituted for the mean sun in Figure 2, it readily can be shown that the hour angles of the apparent sun, and the local apparent times, at any two places differ as the longitudes of those places.

USES OF APPARENT TIME.

13. When the navigator observes the sun to determine his position, or to determine the error of the compass, one of the coordinates he requires is the sun's hour angle, which is found by the use of local apparent time.

FINDING THE HOUR ANGLE OF THE SUN.

14. The local apparent time is equal to the hour angle of the sun plus twelve hours, dropping twenty-four hours if the sum exceeds that amount. In finding the hour angle of the sun from the local apparent time it is convenient to state this in

(a) (b)

a different way. Refer to the figures below. In Figure (a), let the sun be anywhere west of the meridian. It will be seen that L.A.T. = H.A. + 12 hours. In Figure (b), let the sun be anywhere east of the meridian. It will be seen that in this case L.A.T. = H.A. − 12.

Two cases for finding the sun's hour angle result from the above:
(1) Sun west of the meridian, L.A.T. = H.A. + 12^h, and H.A. = L.A.T. − 12^h.
(2) Sun east of the meridian, L.A.T. = H.A. − 12^h, and H.A. = L.A.T. + 12^h.

PROBLEMS:

Given the following data, find the Greenwich apparent time and thence the local apparent time and the H.A. of the sun at the place whose longitude is given.

	Watch.	C-W.	Chro. Error.	Long.	Date.
1.	8–04–31	4–14–08	1^m–49^s fast	68°–17′–00″ W.	May 1, p.m.
2.	4–05–22	5–14–28	1^m–49^s fast	68°–17′–00″ W.	May 1, p.m.
3.	4–51–20	3–31–23.5	3^m–41.1^s slow	121°–08′–25″ E.	Jan. 3, a. m.
4.	4–22–16	3–51–20.5	3^m–41.1^s slow	121°–08′–25″ E.	Jan. 3, p.m.
5.	11–01–01	1–57–54	1^m–05^s slow	30°–00′–00″ W.	Jan. 2, p.m.
6.	1–01–07	9–57–48	1^m–05^s slow	30°–00′–00″ E.	Jan. 2, a.m.
7.	7–07–19	2–44–42	4^m–01^s fast	139°–30′–00″ E.	Jan. 4, a.m.

ANSWERS:

1. G.A.T. 00–19–48.9, L.A.T. 19–46–40.9; H.A. 7–46–40.9.
2. G.A.T. 21–20–59, L.A.T. 16–47–51.0; H.A. 4–47–51.0.
3. G.A.T. 20–22–11.3, L.A.T. 4–26–17.2; H.A. 16–26–45.0.
4. G.A.T. 8–12–50.5, L.A.T. 16–17–24.2; H.A. 4–17–24.2.
5. G.A.T. 0–55–41.4, L.A.T. 22–55–41.4; H.A. 10–55–41.4.
6. G.A.T. 22-56–11.8, L.A.T. 0–56–11.8; H.A. 12–56–11.8.
7. G.A.T. 21–42–50, L.A.T. 19–00–50; H.A. 5–59–10.0.

8. Find to the nearest tenth of a second the L.C.T. of a place whose longitude is 75° W., at the instant the L.A.T. is 8–00–00, October 4, 1925.

ANSWER: 7–48–49.

FINDING THE TIME OF TRANSIT OF THE SUN.

15. The instant of the transit of a celestial body is of particular use to the navigator because at this instant the latitude is most readily and accurately determined. For the sun the instant of transit is local apparent noon, and when the longitude is known, is predicted as follows:

At the instant of local apparent noon the L.A.T. is 12^h–00^m–00^s. The longitude applied to this time, will give the G.A.T. of local apparent noon. For this instant the equation of time is selected and applied to the G.A.T., with sign reversed, the result being the G.C.T. of L.A.N. To this the chronometer error is applied, and the result is the chronometer reading at local apparent noon. The navigator's watch is then compared with the chronometer, and C-W obtained. This, subtracted from the computed chronometer time of L.A.N. will give the watch time of local apparent noon.

EXAMPLE: Find the watch time of local apparent noon on October 4, 1925, at a place whose longitude is 63°–53′ W. The chronometer is fast 01^m–27^s, C-W 4^h–04^m–16^s.

L.A.T. of L.A.N.,		12–00–00	Oct. 4.
Long. W.,		4–15–32	
G.A.T. of L.A.N.,		16–15–32	Oct. 4.
Eq. T. (sign reversed),	(−)	11–13.4	
G.C.T. of L.A.N.,		16–04–18.6	
Chron. error, fast,		1–27.0	
Chro. face at L.A.N.,		16–05–45.6	
C-W,	(−)	4–04–16	
Watch time of L.A.N.,		12–01–29.6	

PROBLEMS: Find the watch time of L.A.N. in the following cases.

	Longitude.	Date.	Chro. Error.	C-W.
1.	23°–17′ E.	May 2	2^m–21.1^s slow	10–23–00
2.	58°–26′–30″ W.	Jan. 1	1^m–05^s fast	3–04–51
3.	177°–45′ E.	Oct. 4	1^m–59.2^s slow	11–58–46
4.	120°–16′–15″ W.	July 1	1^m–31.1^s fast	8–02–10

ANSWERS:

1. 11–58–29. 2. 12–53–39.8. 3. 11–57–13.8. 4. 12–04–03.4.

SIDEREAL TIME.

16. In the presentation of the subject of solar time it was shown that while the earth rotates upon its axis 366.24+ times a year, the sun makes only 365.24+ apparent revolutions, the loss of one apparent revolution being caused by the earth's revolution about the sun. In the case of the stars the earth's revolution does not have the same effect, for the stars are at such a great distance outside of the earth's orbit that the latter is of insignificant size and the earth's movement in it causes no apparent motion of the stars. This being so, the apparent motion of the stars is caused solely by the earth's rotation. It is therefore uniform and at the rate of 366.24+ revolutions per year. The rate of change of hour angle of the stars is therefore different from the rates of both the true and the mean suns, so that neither apparent nor mean time can be used directly to determine star's hour angles. For this purpose it is necessary to use a time based upon the apparent motion of the stars. This is known as sidereal time.

The vernal equinox being at an infinite distance from the earth, its apparent motion, like that of the stars, is unaffected by the earth's revolution. Its rate of change of hour angle therefore serves as a measure of sidereal time. Since the vernal equinox also serves as the point of origin for the measurement of right ascensions, which are similar to hour angles, but measured to the eastward, there is a definite relationship between sidereal time and right ascensions.

The sidereal day is the interval of time between two successive *upper* transits of the vernal equinox at the same meridian. It is divided into twenty-four hours numbered from 0 to 24.

The sidereal time at any place at any instant is equal to the hour angle of the vernal equinox from that place at that instant. Note the difference from solar time which is equal to the hour angle of the sun *plus twelve hours*, the difference being due to the fact that the sidereal day begins at upper transit of the vernal equinox and the solar day at lower transit of the sun. Sidereal noon at a place is the instant of the upper transit of the vernal equinox at that place.

If the vernal equinox is substituted for the mean sun in Figure 2, it may be shown that the sidereal times at two places differs as the longitudes of those places.

RELATION BETWEEN CIVIL AND SIDEREAL TIME.

17. An expression which represents the civil time of an instant may be interpreted in two ways. First, it may be read as an expression of the angular distance of the mean sun from the lower branch of the meridian. Second, it may be used as an expression of the amount of duration that has elapsed since the mean sun crossed the lower branch of the meridian. Similarly an expression which represents the sidereal time of an instant may be used in the same two ways, first as an expression of the angular distance of the vernal equinox from the meridian, and second, as an expression of the amount of duration that has elapsed since the vernal equinox crossed the meridian. It is evident that when a civil time and a sidereal time are used in the first sense, as expressions of angular measurement, they are in the same units, those of angular measurement. In this sense a civil time and a sidereal time may be combined without conversion, just as any angular measurement may be added to or subtracted from another angular measurement to obtain their sum or difference.

When a sidereal time and a civil time are used as expressions of duration, as distinguished from expressions of position, they are in different units. Since a solar year is equal to 365.2422 civil days or 366.2422 sidereal days, the relation between the two sets of units is obtained from the fact that 365.2422 civil days equal 366.2422 sidereal days. The sidereal day is shorter than the civil day by 3 minutes, 55.909 seconds of mean solar time; and sidereal hours, minutes, and seconds are proportionally shorter than civil hours, minutes, and seconds.

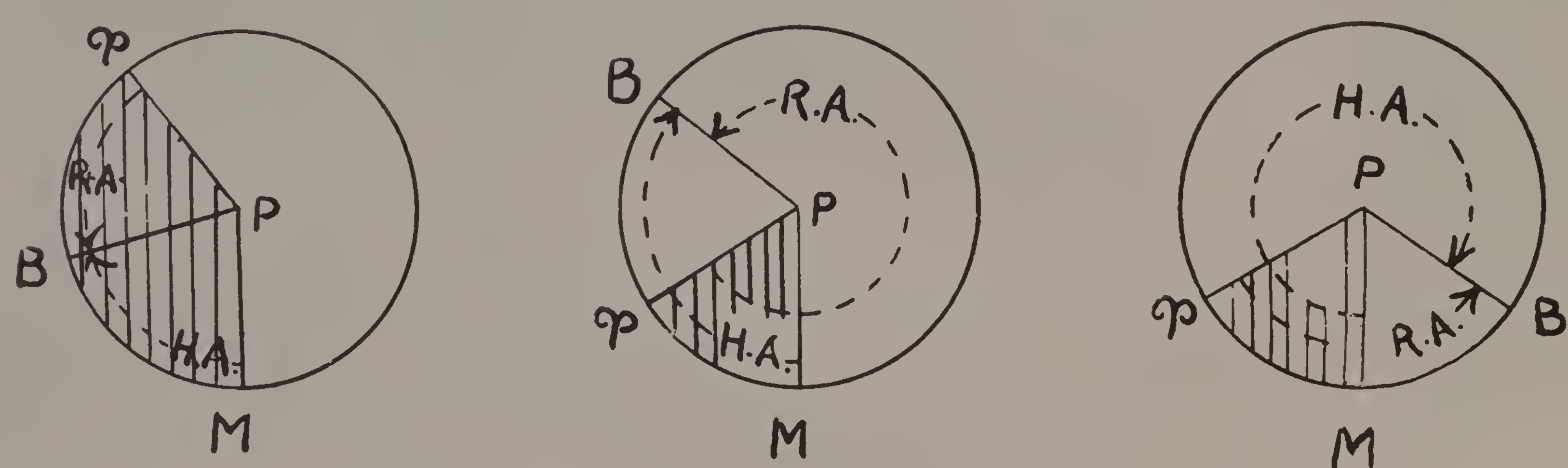
Since the units of civil and sidereal time represent unequal amounts of duration, two periods of time, one expressed in civil units, and the other sidereal units, cannot be combined to find the sum or difference of the periods without converting one to the terms of the other. This may be accomplished readily by means of Tables II and III of the Nautical Almanac, or Tables 8 and 9 of Bowditch, the computation of these tables being based on the relationship explained in the preceding paragraph.

RELATION OF THE SIDEREAL TIME TO THE HOUR ANGLE AND RIGHT ASCENSION OF ANY BODY.

18. In the diagrams of Figure 5, the circle represents the equinoctial, and P the pole. PM is the meridian of any place, PB the hour circle of a celestial body, and ♈ is the vernal equinox. The arc M♈ representing the local sidereal time (L.S.T.) of the place is shaded. The right ascension (RA) and the hour angle (HA) of the body are indicated by dotted lines.

Figure 5.

Case I Case II Case III



In Case I, the hour circle of the body is within the arc which measures the local sidereal time. By inspection L.S.T. = RA + HA.

In Case I, the hour angle plus the right ascension cannot exceed 24 hours. There are two other possible cases, and in these the sum of the hour angle plus right ascension must exceed 24 hours.

In Case II, the hour circle of the body is outside the arc which measures the local sidereal time, and to the west of the local meridian.

$$\text{L.S.T.} = \text{MPB} - ♈\text{PB} = \text{HA} - (24 - \text{RA}) = \text{HA} + \text{RA} - 24.$$

In Case III, the hour circle of the body is outside of the arc which measures the local sidereal time but to the eastward of the local meridian.

$$\text{L.S.T.} = \text{BP}♈ - \text{BPM} = \text{RA} - (24 - \text{HA}) = \text{RA} + \text{HA} - 24.$$

Therefore, as these are the only possible cases, the local sidereal time of a meridian is equal to the right ascension plus the hour angle of a celestial body, dropping 24 hours if the sum exceeds that amount.

The above rule enables a navigator to determine sidereal time without the use of a sidereal clock. From his chronometer he obtains the Greenwich civil time. This is the hour angle of the mean sun from Greenwich plus 12 hours. The right ascension of the mean sun plus 12 hours may be found by the use of the Nautical Almanac for any instant of G.C.T. Since the same relation exists between the hour angle plus 12 hours and the right ascension plus 12 hours, as exists between the hour angle and the right ascension, the G.C.T., as obtained by chronometer, and the R.A.M.S. + 12 hours, as obtained from the Almanac, may be added to obtain the G.S.T. The local longitude applied to this will give the local sidereal time.

In the above discussion the terms civil and sidereal time were both used in the first sense, as expressions of position, not as expressions of duration. The Greenwich civil time expressed the angular distance of the mean sun west of the lower branch of the meridian. To this was added the right ascension of the mean sun plus 12 hours. This, also, was an angular measurement. The sums of these two gave as a result another angle which expressed the distance of the vernal equinox west of the Greenwich meridian. This is all a matter of the position, relative to each other, of three points, the Greenwich meridian, the mean sun, and the vernal equinox. Now having by this means ascertained the hour angle of the vernal equinox, that is, the sidereal time, the latter term may be used in its second sense, as a measure of duration, and in this sense it means that at the instant under consideration, so many hours, minutes, and seconds, of *sidereal time* have elapsed since the vernal equinox crossed the meridian of Greenwich.

TO FIND THE L.S.T. AT THE INSTANT OF AN OBSERVATION.

19. As proved above G.S.T. = G.C.T. + R.A.M.S. + 12 hours. Pages 2 and 3 of the Nautical Almanac tabulate the R.A.M.S. + 12 hours for the instant of 0 hours at Greenwich for every day of the year. At the foot of these pages is a table headed: "Correction for Longitude from Greenwich." This is the correction which must be applied to find the R.A.M.S. + 12 hours for the instant of 0 hours at any other meridian, or to determine the change in the R.A.M.S. that has taken place in a given mean time interval after Greenwich 0 hours. It is in this second manner that the navigator most frequently uses the correction. In fact, for the beginner in navigation, it would be an aid to the understanding of sidereal time if the tables on pages 2 and 3 were headed "R.A.M.S. + 12 hours at 0 hours, Greenwich Civil Time" and "Corrections for Greenwich Civil Time Past Greenwich 0 Hours," since they are first used in those ways.

The G.C.T. and date of the instant of any observation having been found by chronometer, the R.A.M.S. + 12 hours is selected for 0 hours of the date, from page 2 or 3 of the Almanac, and corrected for the time past Greenwich 0 hours by use of the table at the bottom of the pages. Or this correction may be made more conveniently without interpolation, by the use of Table III, pages 110–111 of the Almanac, or Table 9 of Bowditch. The G.C.T. plus the corrected R.A.M.S. + 12 hours will give the G.S.T. of the observation. The longitude is then applied to find the L.S.T.

Although convenient, the use of Table III of the Almanac or Table 9 of Bowditch as described above, is sometimes misleading since those tables are named: "Mean Solar into Sidereal Time."

The use of these tables may be explained in this way. The number of sidereal units in a given period of duration is greater than the number of civil time units in the same period. This difference is caused by, and is equal to, the movement of the mean sun in right ascension during the period. Hence a tabulation of the larger number of sidereal units in a given civil time interval is also a tabulation of the increase in the sun's right ascension in the interval, but when it is used as such the process is not one of conversion of time, but of determining the change in the sun's right ascension.

Example: Given the following data, find the L.S.T., Watch 6–40–20, C-W 4–26–19, Chro. slow 2^m–05^s, Long. 67°–16′ W., Date, 2 January, 1925, p.m.

Watch	6–40–20	
C-W	4–26–19	
Chro.	11–06–39	
Chro. slow	2–05	
G.C.T.	23–08–44	2 Jan.
R.A.M.S. + 12	6–44–27	
Cor. for G.C.T.	3–48.1	
G.S.T.	5–56–59.1	(rejecting 24 hours)
Long. W.	4–29–04	
L.S.T.	1–27–55.1	

FINDING THE HOUR ANGLE OF CELESTIAL BODIES.

20. The right ascension of any celestial body used in navigation may be found in the Nautical Almanac as will be explained later. Having found the local sidereal time in the manner described in the preceding paragraph, and the right ascension from the Nautical Almanac, the hour angle is found from the equation L.S.T. = HA + RA, or HA = L.S.T.—RA.

For a Star. The right ascension of the principal navigational stars may be found for the first day of any month on page 94 of the Nautical Almanac. It will be noticed that the monthly change is very small, so that in the case of a star it will be sufficiently accurate to use the right ascension for the nearest first of the month. Pages 98 and 99 give the right ascensions of certain additional stars for the first day of the year, together with a table of the annual variations with which a rough correction may be made for the month.

EXAMPLE: Find the hour angle of the star α Lyrae (Vega) on 13 January, at the instant when the L.S.T. is 12–54–16.

L.S.T.	12–54–16	
☆'s R.A.	18–34–21.8	(from p. 94, N.A.)
H.A.	18–19–54.2	

FOR A PLANET. The right ascension is given on pages 78–93 for 0^h of every Greenwich date. The daily difference appears as a sub notation. By means of the daily difference and the known G.C.T. the interpolation for the instant may be made and a correction applied to the recorded value of the right ascension for Greenwich 0 hours. This interpolation may be made by use of Table IV, pages 112-114 of the Almanac, but as this table is arranged for only 12 hours the interpolation may have to be made backward from the following day. (Note: The right ascensions of the planets, except Venus, are always increasing. At certain periods of some years the right ascension of Venus decreases, and the correction for G.C.T. must be applied accordingly.)

EXAMPLE: Given the following data, find the hour angle of Venus. Date, 2 January, 1925, a.m. Watch 5–13–00, C-W 5–45-05, Chro. slow 1^m 01^s, Long. 93–47–30 E.

Watch	5–13–00				
C-W	5–45–05				
Chro.	10–58–05				
Chro. slow	1–01				
G.C.T.	22–59–06	1 Jan.	R.A.♀ 2 Jan.	16–50–38, Gr. 0^h	
R.A.M.⊙	6–40–30.4		Cor. IV 1^h–1^m	13	(sign reversed)
Corr. Table III	3–46.5		R.A.♀	16–50–25	
G.S.T.	5–43–22.9	(rejecting 24^h)			
Long. E.	6–15–10				
L.S.T.	11–58–32.9				
R.A. ♀	16–50–25				
H.A.	19–08–07.9				

FOR THE MOON. The right ascension of the moon is given in the Nautical Almanac (pages 30–75) for every even hour of Greenwich civil time. Each right ascension given is followed by a sub notation of the difference in seconds for the two houı period. Table IV may be used for interpolation to find the right ascension at any intermediate period of G.C.T. using the difference for two hours, and the minutes above a two hour period, as the arguments at the top of the page and in the left hand column respectively. As the table is constructed for only one hour, it will be necessary to interpolate backward for time differences of more than one hour.

EXAMPLE: Find the local hour angle of the moon at a place whose Long. is 36°–24′–00″ W., at the instant when the G.C.T. is 18–50–29, 3 January, 1925.

G.C.T.	18–50–29	3 Jan.	R.A.☾, 18^h	2–11–27	
R.A.M.S.	6–48–23.5		Cor. for 50^m–29^s	1–39	(Table IV)
Cor. III	3–05.7		R.A.☾	2–13-06	
G.S.T.	1–41–58.2				
Long. W.	2–25–36				
L.S.T.	23–16–22.2				
☾'s R.A.	2–13–06.0				
☾'s H.A.	21–03–16.2				

FINDING THE TIME OF TRANSIT OF A STAR, A PLANET, OR THE MOON.

21. As previously explained under apparent time, it is useful for the navigator to be able to predict the time of local transit of celestial bodies, for it is at this instant that the latitude is most readily and accurately determined.

FOR A STAR. The Nautical Almanac tabulates, on page 96, the G.C.T. of transit at Greenwich of the stars commonly used in navigation. This tabulated time is given only to the nearest minute, and for the first day of each month. On page 97 is a table of corrections to be applied to find the G.C.T. of Greenwich transit for any other day of the month. Having found the G.C.T. of Greenwich transit for the required date, the L.C.T. of local transit for that date may be found by applying a correction for the local longitude. This correction is a part of the difference in the times of transit for the given date and the next succeeding day, as tabulated on page 97, proportional to the local longitude, expressed in time, divided by 24 hours. It is to be added for east longitudes and subtracted for west longitudes. Having thus found the L.C.T. of local transit, apply the longitude in time to obtain the G.C.T. of local transit. Apply to this the chronometer error, and obtain the chronometer reading at local transit. Subtract from this the C–W, and the result will be the watch time of local transit. This result is correct only to the nearest minute.

Example: Find the watch time of transit of the star α Virginis (Spica) on 2 January, 1925, at a place whose longitude is 67°–30′ W., chro. slow 1^m–06^s, C-W 4–32–19.

Approx. G.C.T. of Gr. Transit, 1 Jan.		6–40–00	(p. 96, N.A.)
Cor. for 2 Jan.	(–)	04–00	(p. 97, N.A.)
Approx. G.C.T. of Gr.Transit, 2 Jan.		6–36–00	
Cor. for Long. W., $= +4^m \times \frac{4.5}{24} =$	(–)	45	
L.C.T. of local transit		6–35–15	
Long. W.		4–30–00	
G.C.T. of local transit		11–05–15	
Chro. error, slow		1–06	
Chro. reading at local transit		11–04–09	
C-W (subtract)		4–32–19	
Approx. Watch time of local transit		6–31–50	

The above method gives the watch time of transit correct to the nearest minute. This is accurate enough if the altitude of the body *at transit* is obtained. If, however, the altitude at transit is missed, due to clouds, but obtained near transit, the latitude may be obtained by a form of meridian altitude sight known as the reduction to the meridian. Moreover, the period of twilight when it is dark enough for the stars to be clearly discernable, and still light enough for the horizon to be clearly defined, is so brief that it is seldom advisable to wait for the transit of the star. It is generally better to take the altitude when the conditions of visibility are best for an accurate observation, and use the method of the reduction to the meridian. This requires an exact watch time of transit, which is easily found as follows:

At the instant of transit the L.S.T. is equal to the body's right ascension, for the hour angle is then zero, and the equation L.S.T.=R.A.+H.A. becomes L.S.T.=R.A. The star's right ascension may be selected from the Nautical Almanac with only an approximate knowledge of the date, and is equal to the L.S.T. at local transit. The longitude applied to this will give the G.S.T. at local transit. It is now necessary to fix the Greenwich date at local transit. This can be done by finding (from page 96, N.A.) the G.C.T. of Greenwich transit for the given date and applying the longitude. For the Greenwich date of local transit select the G.S.T. of Greenwich 0^h. Subtract from this the G.S.T. of local transit. The result is the period of time, expressed in sidereal units, that will have elapsed from Greenwich midnight to the time of local transit. Convert this to a mean time interval. The result is the G.C.T. of local transit.

Example: Solve the last example by the exact method.

☆'s R.A.=L.S.T. of L.Tr.=		13–21–13.5	G.C.T. of Gr.Tr. 2 Jan.	6–36–00
Long. W.		4–30–00	Cor. for Long. W. (–)	–45
G.S.T. of L.Tr.		17–51–13.5	L.C.T. of L.Tr. 2 Jan.	6–35–15
G.S.T. of Gr. 0^h (RAMS+12)		6–44–27	Long. W.	4-30–00
Sid. Int.		11–06–46.5	G.C.T. of L.Tr.	11–05–15
Cor. Table II	(–)	1–49.2		
G.C.T. of local transit		11–04–57.3		
Chro. error, slow		1–06.0		
Chro. reading at L.Tr.		11–03–51.3		
C-W		4–32–19		
Watch time of L.Tr.		6–31–32.3		

For a Planet. The Nautical Almanac, pages 78–93, gives for each day of the year the G.C.T. of Greenwich transit to the nearest minute. From G.C.T. of Greenwich transit for the given date the L.C.T. of local transit may be obtained by a simple interpolation for longitude between the given date and the adjacent date, interpolating forward for west longitude, and backward for east longitude. Then proceed as for a star.

Example: Find the watch time of transit of the planet Venus on 2 January, 1925. at a place whose longitude is 67°-45′-45″ E., chro. slow 1^m–06^s, C-W 7-29-45.

Approx. G.C.T. of Gr. Transit, 2 Jan.		10–07–00	
Cor. for longitude	(−)	00–11.3	
L.C.T. of local transit		10–06–48.7	
Long. E.		4–31–03	
G.C.T. of local transit		5–35–45.7	(2 Jan.)
Chro. slow	(−)	1–06	
Chro. reading at L.Tr.		5–34–39.7	
C-W (subtract)		7–29–45	
Approx. Watch time of local transit		10–04–54.7	

If a more exact determination is required it may be had by finding the approximate G.C.T. of local transit as above, then finding the right ascension of the planet for that instant and proceeding as in the exact determination for a star.

For the Moon. The problem of predicting the time of local transit of the moon is similar to that for a planet, but the right ascension changes much more rapidly and therefore the daily difference in the G.C.T.'s of Greenwich transits is larger. See pages 76–77, Nautical Almanac. This requires a more accurate interpolation, which, however, is facilitated by the use of Table 11, Bowditch, which is self explanatory.

Example: Find the watch time of local transit of the moon at a place in Long. 23° W., on 2 January, 1925. Chro. fast 1^m–59^s, C-W 1–35–15.

Approx. G.C.T. of Greenwich transit, 2 Jan.		18–38–00	
Cor. for Long. (Table 11, Bowditch)	(+)	2–36	
Approx. L.C.T. of local transit		18–40–36	
Long. W.		1–32–00	
Approx. G.C.T. of local transit		20–12–36	
Chro. fast		1–59	
Approx. Chro. reading at local transit		20–14–35	
C-W (subtract)		1–35–15	
Approx. Watch time of local transit		6–39–20	(rejecting 12^h)

The exact time of local transit may be found as explained for a planet.

Note: Since the lunar day is longer than the solar day there are certain dates on which no transit of the moon occurs at certain places.

Example: Find the L.C.T. of transit of the moon at a place in Long. 135° E., on 7 June, 1925.

G.C.T. of Greenwich transit, 7 June		0^h–06^m	
Cor. for Long. 135° E. (Table 11)	(−)	23	
L.C.T. of local transit		23-43	6 June

Since the next transit will not take place for about 24 hours and 50 minutes, it is apparent that there will be no transit of the moon at this place on 7 June.

Again it sometimes happens, when the G.C.T. of Greenwich transit occurs near 0^h or 24 hours that it is necessary to work from a Greenwich date which differs by one from the local date.

Example: Find the L.C.T. of transit of the moon on 6 June, at a place whose longitude is 60° E. The Almanac gives no transit of the moon for Greenwich on 6 June, but gives 0^h–06^m as the G.C.T. of Greenwich transit on 7 June.

G.C.T. of Gr. Tr. 7 June, $=0^h$–06^m		$= 24^h$–06^m	6 June
Cor. for 60° E. Long.	(−)	10	
L.C.T. of local transit		23–56,	6 June

CHAPTER II.

OBSERVATIONS FOR LATITUDE.

MERIDIAN ALTITUDES.

22. The simplest method of determining latitude at sea by means of observations of celestial bodies is that known as the meridian altitude. In this method the sextant altitude of a celestial body is taken when it is on the observer's meridian and corrected to give the true geocentric altitude of the body's center. This altitude is then combined with the body's declination to determine the latitude by one of the methods explained below, the determination being based upon the fact that the latitude of a place is equal to the declination of its zenith, and also to the altitude of the elevated celestial pole. Proof: In Figure I let the inner circle represent the terrestial meridian of a place, Z′, in north latitude, and the outer circle the celestial meridian. E′ Q′ is the equator, EQ the equinoctial. nP and nP′ are the celestial and terrestial poles. H′R′ is the terrestial horizon, and NOS the celestial horizon to which the altitude of all celestial bodies and points are reduced.

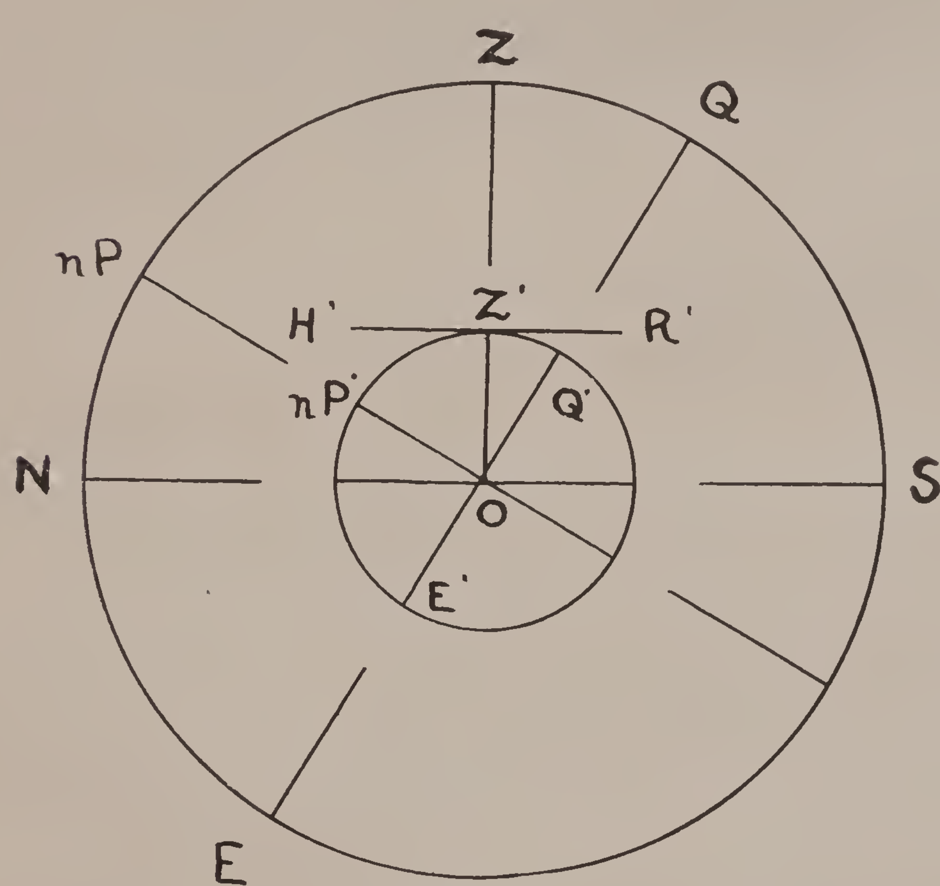


Fig. 1.

Then Z′OQ′ is the latitude of the place Z′. It is equal to ZOQ, which is the declination of the zenith.

By inspection ZOQ = nPON, the altitude of the elevated pole.

Therefore, the latitude of a place is equal to the declination of the zenith or the altitude of the elevated pole.

Figure 1 is not in proportion since the celestial sphere is not shown of infinite radius as compared to the radius of the earth, but as only angles measured from the earth's center are considered the deductions are correct.

When the figure is drawn in proportion, the earth reduces to a point at the center of the celestial sphere, as in Figure 2. In this figure a celestial body to be visible must be above the horizon, in the unshaded portion. Such a body at transit may be on the meridian in either of the sectors 1, 2, 3, or 4.

If it is on the meridian in sectors 1 or 2, it will bear toward the depressed pole, *i. e.*, if the observer is in north latitude the body will bear south and vice versa. Similarly if the body is in sectors 3 or 4 it will bear north from an observer in north latitude and south in south latitude. The figure is drawn for north latitude, and N and S are the north and south points of the horizon. If P represents the south pole N and S will be interchanged.

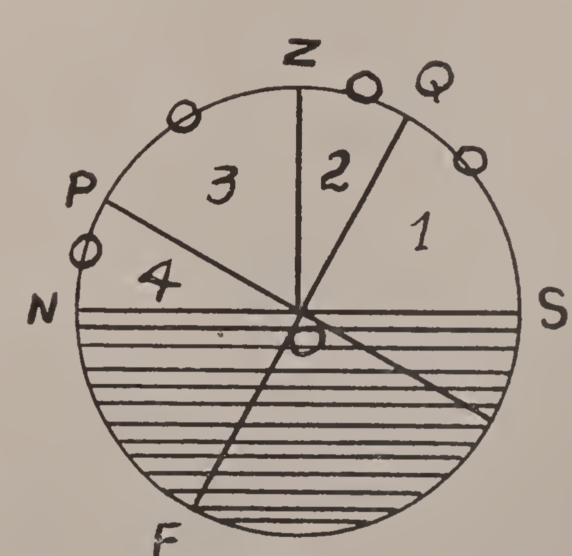


Fig. 2.

Denoting the body's declination by d, its polar distance, (90—d), by p, its altitude by H, and its zenith distance, (90—H), by Z, we have, if the body is in sector 1,

$$\text{Lat.} = ZQ = Z - d = (90° - H) - d$$
$$\text{In sector 2, Lat.} = ZQ = Z + d = (90° - H) + d$$
$$\text{In sector 3, Lat.} = ZQ = PN = H - p = H - (90° - d)$$
$$\text{In sector 4, Lat.} = ZQ = PN = H + p = H + (90° - d)$$

Therefore the latitude of a place may be determined by observing the sextant altitude of a body at transit, correcting the observed altitude to obtain the geocentric altitude of the body's center, selecting the body's declination from the Nautical Almanac, and combining the altitude and declination in accordance with that one of the above equations which fits the case.

FINDING THE DECLINATION.

23. The declination of the sun is tabulated in the Nautical Almanac with the equation of time, and the method of selecting it for any given instant of G.C.T. is the same as that already explained for the latter.

The declinations of the moon, of the planets, and of the stars are tabulated with their right ascensions and the method of selecting them for any instant of G.C.T. is the same as that already explained for the latter.

For the meridian altitude of the sun, the moon, or a planet, the declination should be selected for the G.C.T. of the time of transit. The declination of a star changes so slowly that it may be selected for the nearest first of the month without correction.

24. In the examples standard symbols for altitude will be used as follows:

h_s, the altitude as observed with the sextant.

h, the sextant altitude corrected for I.C.

H_o, the sextant altitude with all corrections applied, that is the true geocentric altitude of the center.

H_c, the calculated geocentric altitude of the center.

H_a, the approximate altitude.

NOTE.—As an exercise, in the following examples and problems, the longitude at time of sight is given, and the watch time at which the sight is to be taken is required. The problems, therefore, simulate the solution for latitude for a ship on a north or south course, (with an unchanging longitude). Practically, when underway with a changing longitude, one of the following methods is preferable.

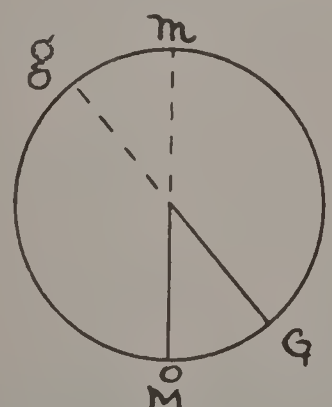
(a) For the sun. To determine the W.T. of transit by Todd's method, to be explained hereafter.

(b) For any other body. To use the prospective longitude at time of sight as in the above problems, to determine the prospective W.T. of transit. Then to take the observation at *about* that watch time, choosing, however, the instant of best visibility, steadiness of the ship, etc. The *actual* watch time of sight is then noted and used in the solution, the D.R. longitude for that instant determined, and the body's "t" determined, by the method of Art. 20. The solution will then be either by the method of meridian altitude, or reduction to the meridian, according as "t" is, or is not, zero.

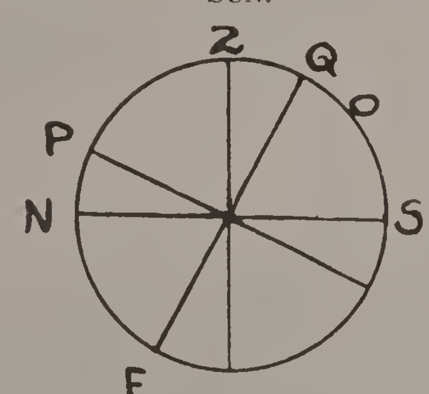
EXAMPLE: At sea, 2 January, 1925, the noon position by D. R. is Lat. 33°–19′ N., Long. 45°–17′ W. The navigator observes the sun at L.A.N. bearing south, as follows. h_s 33°–35′–30″, I.C. (−) 1′–00″, height of eye, 31 feet, C-W 3–03–09, chro. slow 1^m–04.9^s. Find the W.T. of L.A.N. and the latitude by observation.

MERIDIAN ALTITUDE, SUN.

2 JAN., 1925, L.A.N.



SUN.



Lat. 33°–19′ N.

λ 45°–17′ W.

= 3^h–01^m–08^s

$L = z - d = 90° - (H_o + d)$

L.A.T. of L.A.N.	12–00–00	(2 Jan.)
λ (W)	3–01–08	
G.A.T. of L.A.N.	15–01–08	(2 Jan.)
Eq.T. (sign reversed) (+)	4–07	
G.C.T. of L.A.N.	15–05–15	(2 Jan.)
Chro. slow	1–04.9	
C.T. of L.A.N.	15–04–10.1	
C-W (subtract)	3–03–09	
W.T. of L.A.N.	12–01–01.1	

h_s		33–35–30
Cor.	(+)	8–32
H_o		33–44–02
d		22–55–48
H_o+d		56–39–50
$90-(H_o+d)$		33–20–10 N.
=Lat.		

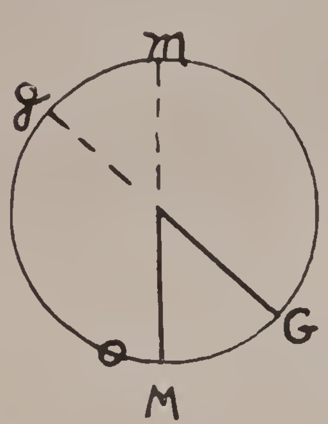
I.C.	(−)	1–00
T. 46	(+)	9–14
Sub.	+	0–18
Cor.	(+)	8–32
dec.		22–56.0 S.
Cor.	(−)	.2
d		22–55.8 S.
H.D.	(−)	0′.2
Int.		1.1
Cor.	(−)	.22

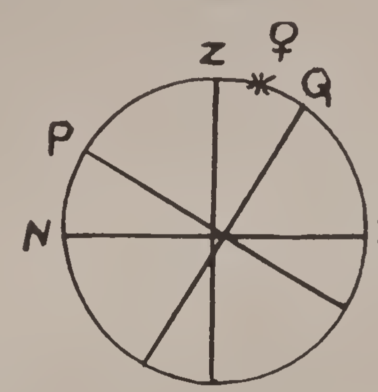
Eq.T.	(−)	4^m–$05^s.8$
Cor.	(+)	1.2
Eq.T.		4–07.0
H.D.	(+)	1.2
Int.		1
Cor.	(+)	1.2

Example: At sea, 4 July, 1925, p.m., in D.R. Lat. 37°–53′ N., Long. 59°–24′30″ W., the navigator of a vessel observed the planet Venus on the meridian for latitude. The data were as follows: C-W 4–05–27, chro. fast 6^m–02^s, I.C. (+) 1′–00″, height of eye 36 feet, h_s 73–29–00. Find (a) the approximate G.C.T. of local transit, (b) the exact W.T. of local transit, (c) the approximate altitude at transit to be used as an aid in finding the planet in daylight, (d) the latitude at time of transit.

MERIDIAN ALTITUDE, PLANET.

4 July, 1925, P.M. — Venus.





D.R. Lat. 37°–53′ N.

λ 59°–24′–30″ W.

= 3^h–57^m–38^s

$L = z + d = 90 - H_o + d = 90 + d - H_o$

$Ha = 90 + d - L$

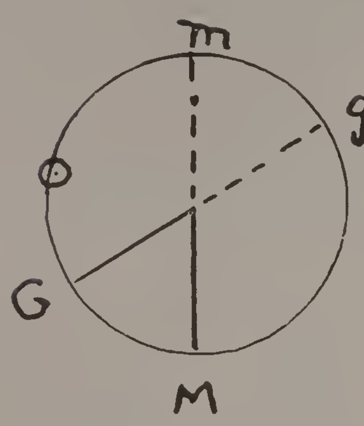
Ap. G.C.T. of Gr.Tr.	13–27–00	(4 July)			90+d=	111–17–12
Cor. for λ (+)	0–10				L	37–53–00
L.C.T. of L.Tr.	13–27–10				Ha	73–24–12
λ (W)	3–57–38					
Ap. G.C.T. of L.Tr.	17–24–48	(4 July)	R.A.	8–12–05	Dec.	21–28.2 N.
			Cor. (+)	3–43	Cor.	11.0
R.A.=L.S.T. of L.Tr.	8–15–48		R.A.	8–15–48	d	21–17.2
λ (W)	3–57–38		D.D.	307″	D.D.	152″
G.S.T. of L.Tr.	12–13–26		Int.	$17.^h41$	Int.	$17.^h41$
R.A.M.S.+12	18–45–56.5		Cor.	3′–43″ (T. IV)	Cor.	11′–00″
Sid. Int.	17–27–29.5					
II	2–51.6		h_s	73–29–00	I.C. (+)	1′–00″
G.C.T.	17–24–37.9		Cor. (−)	5–11	T. 46 (−)	6–11
Chro. fast	6–02		H_o	73–23–49	Cor. (−)	5–11
Chro. T. of L.Tr.	17–30–39.9		90+d	111–17–12		
C-W (subtract)	4–05–27		90+d−H_o	37–53–23 N.		
W.T. of L.Tr.	13–25–12.9 or 1^h–25^m–12.9^s		=Lat.			

EXAMPLE: At sea, 2 May, 1925, p.m., in D.R. position Lat. 7°–18′ N., Long. 61°–23′ E., observed the meridian altitude of the moon's upper limb bearing north as follows: C-W 7–54–47, chro. fast 2^m–19^s, h_s 83°–54′, I.C. (+) 2′–00″, height of eye 28 feet.

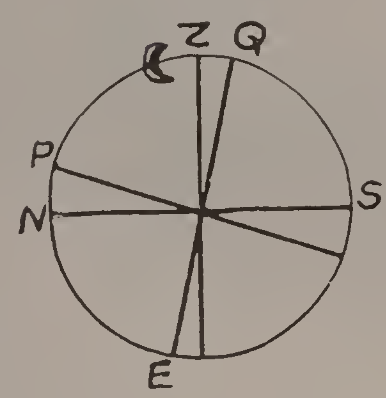
REQUIRED: The approximate G.C.T. of local transit, the exact watch time of the moon's transit, and the latitude at time of sight.

MERIDIAN ALTITUDE, MOON.

2 MAY, 1925, P.M.



MOON.



Lat. 7°–18′ N.

λ 61°–23′ E.

= 4^h–05^m 32^s

$L = d - z = d - (90 - H_o)$

$= d + H_o - 90$

Ap. G.C.T. of Gr.Tr.		19–32–00	(2 May)
Cor., λ, E. (T. 11)	(−)	08–00	
Ap. L.C.T. of L.Tr.		19–24–00	
λ (E.)		4–05–32	
Ap. G.C.T.Q of QL.Tr.		15–18–28	(2 May)
☾'s R.A.=L.S T. of L.Tr.		10–04–15	
λ (E.)		4–05–32	
G.S.T. of L.Tr.		5–58–43	
R.A.M.S.+12		14–37–33.4	
Sid. Int.		15–21–09.6	
Table II		2–30.9	
G.C.T. of L.Tr.		15–18–38.7	
Chro. fast		2–19	
Chro. T. of L.Tr.		15–20–57.7	
C-W (subtract)		7–54–47.0	
W.T. of L.Tr.		7–26–10.7	

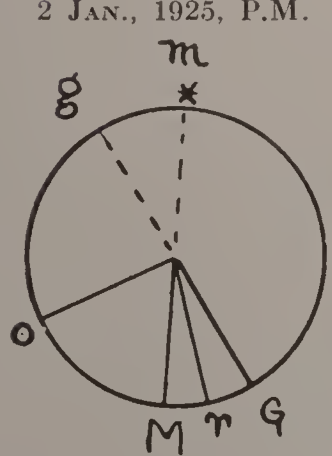
R.A.		10–01–36
Cor.	(+)	2–39
R.A.		10–04–15
Dif. 2 Hrs.		243″
1 Hr.		2′–01″.5
18.5 m.		37′.5
Cor.	(+)	2′–39″.0
h_s		83–54–00
I.C.	(+)	2–00
h		83–56–00
Cor.		14–23
H_o		83–41–37
d		13–38–06
H_o+d		97–19–43
	(−)	90–00–00
Lat.		7–19–43 N.

Dec.	(+)	13–48.8	H.P.=55′.2
Cor.	(−)	10.7	
d		13–38.1	
Dif. 2 Hrs.	(−)	16′.4	
1		8′.2	
18.5 m.		2.5 (T. IV)	
Cor.	(−)	10.7	
T. 49	(−)	15–00	
Eye	(+)	0–37	
Cor.	(−)	14–23	

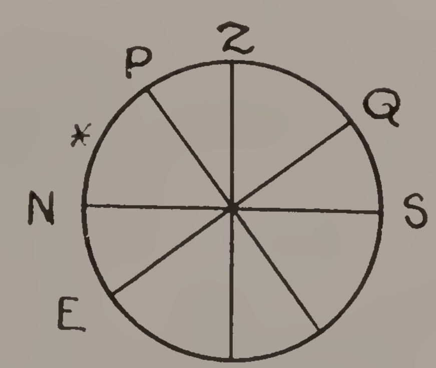
EXAMPLE: At sea, 2 January, 1925, p.m., D.R. position Lat. 51°–13′ N., Long. 19°–30′ W., observed the star α Ursae Major (Dubhe) at lower transit bearing north, as follows: C-W 1–18–19, chro. fast 1^m–01.9^s, I.C. (+) 1′–30″, height of eye 36 feet, h_s 23°–27′–00″. Find watch time of lower transit, and the latitude.

MERIDIAN ALTITUDE, STAR, LOWER TRANSIT.

2 JAN., 1925, P.M.



DUBHE.



Lat. 51°–13′ N.

λ 19°–30′ W.

= 1^h–18^m–00^s

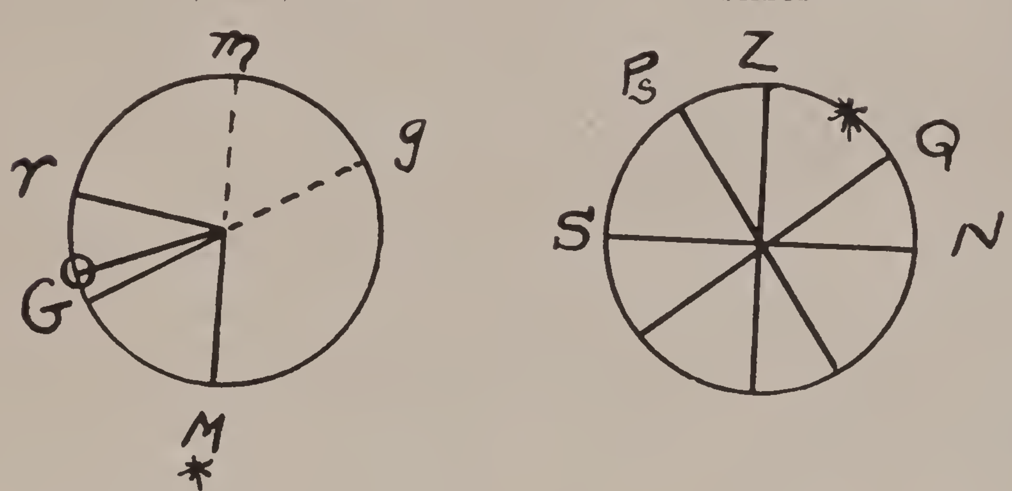
$L = H_o + p = 90 + H_o - d$

★'s R.A.	10–59–06.5	Dec.	62–09.1 N.		
Plus	12–00–00	h_s	23–27–00	I.C.	+ 1′–30″
L.S.T. of L.Tr.	22–59–06.5	Cor.	(−) 6–36	T. 46	(−) 8–06
λ (W.)	1–18–00.0	H_o	23–20–24	Cor.	(−) 6–36
G.S.T. of L.Tr.	24–17–06.5	90+H_o	113–20–24		
R.A.M.S.+12	6–44–27.0	d	(−) 62–09–06		
Sid. Int.	17–32–39.5	Lat.	51°–11′–18″ N.		
II	(−) 2–52.4				
G.C.T. of L.Tr.	17–29–47.1				
Chro. fast	1–01.9				
Chro. T. of L.T.	17–30–49.0				
C-W	1–18–19				
W.T. of L.Tr.	4–12–30 p.m.				

Example: The navigator of the U.S.S. Birmingham in D.R. position, Lat. 60°–15′ S., Long. 55°–50′–30″ E., at about 4:07 p.m., on 1 May, 1925, observes the star Sirius on the meridian as follows: C-W 8–01–15, chro. slow 14^m–25^s, h_s 46°–25′–00″, I.C. (+) 1′–30″, height of eye 45 feet. Find the watch time of transit and the latitude.

MERIDIAN ALTITUDE, STAR

1 May, 1925, P.M. Sirius



Lat. = 60°–15′ S.

λ = 55°–50′–30 E.

= 3^h–43^m–22^s E.

$L = Z + d = 90 + d - H_o$

R.A.=L.S.T. of L.Tr.	6–41–49.8	d =	16–37 S.		
λ (E.)	3–43–22	h_s	46–25–00	I.C.	(+) 1–30
G.S.T.	2–58–27.8	Cor.	(−) 6–01	T. 46	(−) 7–31
R.A.M.S.+12	14–33–36.9	H_o	46–18–59	Cor.	(−) 6–01
Sid. Int.	12–24–50.9	90+d	106–37–00		
Tab. II	2–02	Lat.	60–18–01 S.		
G.C.T. of L.Tr.	12–22–48.9 (1 May)				
Chro. slow	14–25				
C.T. of L.T.	12–08–23.9				
C-W	8–01–15				
W.T. of L.Tr.	4–07–08.9				

REDUCTION TO THE MERIDIAN.

25. It sometimes happens that a body is obscured by clouds at the instant of transit. In this case, should it be possible to observe the altitude shortly before or after transit, the altitude then taken may be corrected, by the method hereafter explained, to obtain the meridian altitude. The method is called the reduction to the meridian.

The paths in which the celestial bodies appear to move are curves which reach their highest point on the observer's meridian. For a small angular distance on either side of the meridian these curves are nearly parallel to the observer's horizon, and consequently as a body moves in its curve near the meridian its change of altitude is relatively slow. While during this period the change in altitude is relatively slow, it is still appreciable and will vary in rate depending on the relation between the observer's latitude and the body's declination. Thus a body which transits high above the observer's horizon will change its altitude more rapidly than one which transits at a low altitude. For the various combinations of the observer's latitude and declinations of celestial bodies the changes of altitude which will occur while a body is changing its hour angle fifteen minutes of arc, either immediately before or immediately after meridian passage, have been computed and are tabulated in Table 26, Bowditch. In computation these tabulated values are designated as "a."

For the sun a change of hour angle of 15 minutes of arc will take place in one minute of apparent time, and for a star in one minute of sidereal time. Since the method of reduction to the meridian is used for small changes of hour angle only, the difference between an apparent time interval and a mean time interval will be inappreciable, and the tabulated values of "a" may be used for mean time minutes without material error. Similarly, in the case of a planet, the change of right ascension during the period it is close to the meridian is so small that such change may be neglected, and minutes of sidereal time may be used for a planet for the tabulated values of "a."

It may be proved by mathematics that if a body changes its altitude "a" seconds while changing its hour angle one minute of time from the meridian, then, in any other small period, say, "t" minutes of time, within the limits of slow movement in altitude, it will change its altitude "at^2" seconds of arc. Hence, knowing the time of transit of a body, and the time of observations near transit, we may find the altitude at transit by applying "at^2" seconds to the observed altitude.

To find "t." For the sun the difference between the computed watch time of noon and the watch time of observation is sufficiently accurate to use as "t." For a star or a planet, if the watch time of transit has been computed by the exact method, the difference between the watch time of transit and observation may be reduced to a sidereal interval and used as "t." Or, if the exact watch time of transit has not been computed the watch time of observation should be converted to L.S.T. The difference between the L.S.T and the body's R.A. is the "t" required. This latter method should always be used for moon sights, because the changes of R.A. and declination of the moon are so rapid that they must be corrected for the G.C.T. of the instant of observation.

To find "a." Table 26 tabulates the values of "a" for latitudes from 0° to 60° combined with declinations from 0° to 63°, thus including the usually navigated waters and the principal celestial bodies used in navigation. Values are omitted for those cases in which the altitude of the body at transit is more than 86° or less than 6°, as results are inaccurate in those cases.

To find "at^2." The values of "at^2" are tabulated in Table 27, Bowditch, for those values of "a" and "t" for which the method is sufficiently accurate. The correction is additive to altitudes observed near upper transit, and subtractive from altitudes observed near lower transit.

Having found the meridian altitude by applying "at^2" to an altitude observed near transit, the latitude is found as explained for meridian altitudes. The resultant latitude, however, is the latitude of the place of observation. In the case of a reduction to the meridian of the sun the latitude should be corrected for the run from noon to obtain the noon latitude.

Example: A destroyer is steaming north (true) at 20 knots. At 12 minutes before L.A.N. an altitude of the sun is taken. The latitude obtained by the method of reduction to the meridian is found to be 30°–10′ N. This is the latitude of the place where the observation was taken. At L.A.N. the destroyer will be four miles north of that place. Therefore, the latitude at L.A.N. will be 30°–14′ N.

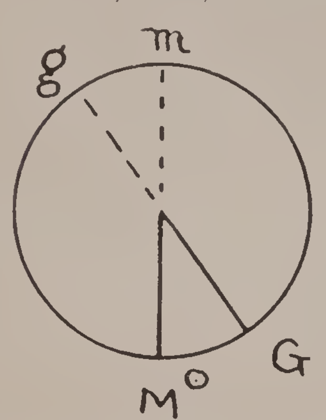
VALUE OF THE DECLINATION TO BE USED IN A REDUCTION TO THE MERIDIAN.

26. In working a reduction to the meridian, the declination should properly be selected for the G.C.T. of the observation. This is necessary for the moon because of its rapid change of declination, but for the other bodies it is sufficiently accurate to use the declination for the G.C.T. of transit.

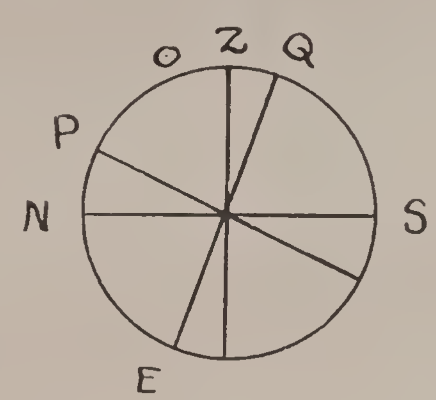
Example: On 3 July, 1925, in D.R. position Lat. 12°-44′ N., Long. 30°–14′–45″ W., the navigator observes the sun for latitude, bearing north, as follows: W 11^h–55^m–21^s, C-W 2^h–05^m–10^s, chro. fast 4^m–15^s, I.C. (+) 2′–00″, height of eye 28 feet. h_s 79°–20′–15″. Find the latitude at time of sight. If, after the observation, the ship continues on her course and speed which are 15° true at 15 knots, what will be the latitude at L.A.N.?

REDUCTION TO THE MERIDIAN, SUN.

3 July, 1925, A.M.



Sun.



Lat. 12°–44′ N.

λ 30°–14′–45″ W.

= 2^h–00^m–59^s

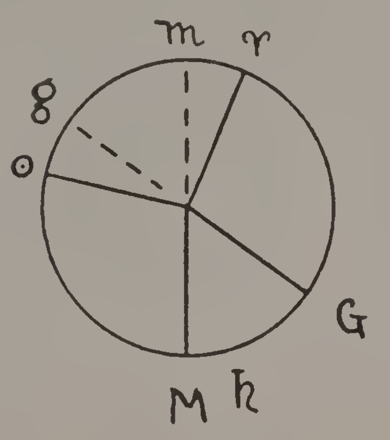
Lat. $= d - z = d - (90 - H_o) = H_o + d - 90$

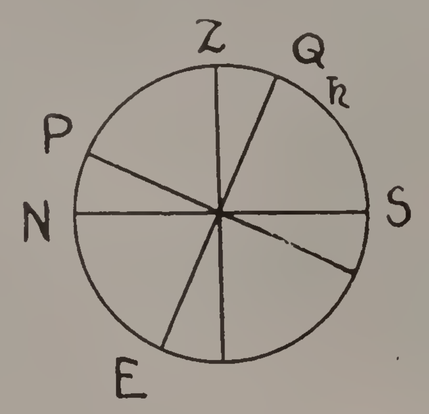
L.A.T. of L.A.N.	12–00–00	h_s	79–20–15	T. 46	(+) 10′–40″		
λ (W.)	2–00–59	Cor. (+)	12–26	I.C.	(+) 2′–00		
G.A.T. of L A.N.	14–00–59	H_o	79–32–41	Sub.	(−) 0–14	Eq.T.	(−) 3–57.1
Eq.T. (sign reversed) (+)	3–57.1	at²	12–24	Cor.	(+) 12–26	Cor.	00
G.C.T. of L.A.N.	14–04–56.1	H_c	79–45–05	⊙'s d	22–59.1N	Eq. T.	3–57.1
Chro. fast	4–15	d	22–59–06	Cor.	0.0	H.D.	0.5
Chro. T. of L.A.N.	2–09–11.1	H_o+d	102–44–11	d	22–59.1N	Int.	0.0
C-W (subtract)	2–05–10	(−)	90–00–00	H.D.	0.2	Cor.	0.0
W.T. of L.A.N.	12–04–01.1	Lat.	12–44–11	Int.	.1		
W.T. of Obs.	11–55–21	Δ L.	2–06	Cor.	.02		
t	8–40.1	Lat. at L. A.N. 12–46–17 N.					
a	9.9						
at²	12′–24″						

Example: At about 7:30 p.m., 3 July, 1925, in Lat. 25°–40′ N., and Long. 46°–50′ W., the navigator observes the planet Saturn bearing south as follows: W 7^h–30^m–30^s, C-W 2^h–59^m–20^s, chro. slow 0^m–50^s, planet's h^s 52°–30′–00″, I.C. 0′–00″, height of eye 30 feet. Find latitude at time of sight by reduction to meridian.

REDUCTION TO THE MERIDIAN, PLANET.

3 July, 1925, P.M. Saturn.





Lat.	25°–40′ N.
λ	46°–50′ W.
=	3^h–07^m–20^s

$L = z - d$

$= 90 - H_o - d = 90 - (H_o + d)$

W		7–30–30	
C-W		2–59–20	
Chro.		10–29–50	
Chro. slow		0–50	
G.C.T.		22–30–40	(3 July)
R.A.M.S.+12		18–41–59.9	
Table III	+	3–41.9	
G.S.T.		17–16–21.8	
Long. (W.)		3–07–20.0	
L.S.T.		14–09–01.8	
R.A. ♄		14–24–32.2	
t		15–30.4 E.	
a		2″.9	
at²		11′–37″	

h_s		52–30–00
Cor.	(−)	6–07
H_o		52–23–53
at²	(+)	11–37
H_c		52–35–30
d		11–44–42
H_c+d		64–20–12
		90–00–00
Lat.		25–39–48N

I.C.		0–00
T. 46	(−)	6–07
Cor.	(−)	6–07
♄'s Dec.		11–44.8 S.
Cor.	(−)	0.1
d		11–44.7
D.D.	(−)	0.1
Int.		22h.5
Cor.	(−)	0.1

R.A.		14–24–35
Cor.	(−)	02.8
R.A.		14–24–32.2
D.D.	(−)	3″
Int.		22h.5
Cor.	(−)	2″.8

THE CONSTANT.

27. The four equations for latitude by the method of meridian altitudes are:

$$L=(90-H_o)-d;\ L=(90-H_o)+d;\ L=H_o-(90-d);\ L=H_o+(90-d)$$

Letting c equal the algebraic sum of the I.C. and the correction from Table 46, Bowditch, and substituting (h^s+c) for H_o, these equations become:

$$L=90-(h_s+c)-d=(90-c-d)-h_s$$
$$L=90-(h_s+c)+d=(90-c+d)-h_s$$
$$L=h_s+c-(90-d)=h_s-(90-d-c)$$
$$L=h_s+c+(90-d)=h_s+(90-d+c)$$

In the latter forms of the equations, the quantities within the brackets may be computed in advance of the observation and are called constants. The computation in advance is accomplished as follows for observations of the sun, for which body the method is principally used:

First. The G.C.T. of L.A.N. is computed, and the declination of the sun selected from the Nautical Almanac for that time. This gives one of the unknown quantities within the brackets.

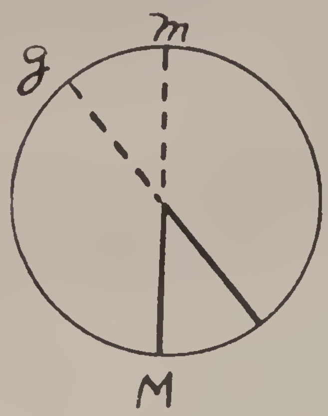
Second. The time of L.A.N. being known, the D.R. latitude for noon may be predicted. This D.R. latitude and the declination as found above are substituted in the equation for latitude and the equation solved for the approximate altitude at noon. For this approximate altitude the correction for altitude is selected from Table 46, Bowditch, the height of eye from which the noon observation is to be taken, the calculated approximate altitude, and the date being the arguments used. With this correction from Table 46, is combined the I.C. of the sextant which will be used for the observation, the result being c. With c and d known, the constant may be computed.

When the constant is found as above, the noon latitude may be found immediately after the sextant altitude at noon is obtained, by simply combining the sextant altitude and the constant. The manner in which they are combined will depend on which one of the four equations governs the case.

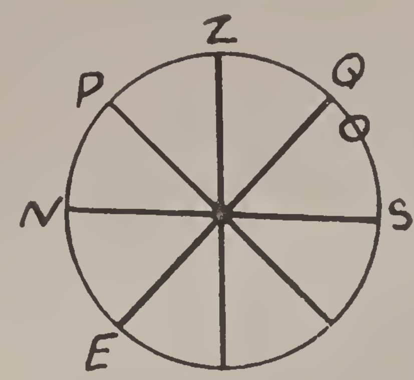
Example: At sea, 1 January, 1925, the predicted L.A.N. position of a ship is Lat. 42°–20′ N., Long. 42°–27′ W., the navigator observes the sun on the the meridian for latitude as follows: C-W 2–48–35, chro. slow 1^m–14^s, I.C. (−) 1′–00″, height of eye 20 feet, h_s 24°–23′–00″. Find the W.T. of L.A.N., the noon constant (K_n) and the latitude.

CONSTANT FOR MERIDIAN ALTITUDE, SUN.

1 Jan., 1925, LAN.



Sun.



Lat.	42°–20′ N.
λ	42°–27′ W.
=	2^h–49^m–48^s

$L = z - d = (90 - H_o) - d$

$= 90 - (h_s + c) - d, \; K = 90 - (c + d)$

$H_a = 90 - L - d = 90 - (L + d)$

L.A.T. of L.A.N.	12–00–00	
λ (W.)	2–49–48	
G.A.T. of L.A.N.	14–49–48	(1 Jan.)
Eq.T. (sign reversed) (+)	3–38.5	
G.C.T. of L.A.N.	14–53–26.5	(1 Jan.)
Chro. slow (−)	1–14	
Chro. T. of L.A.N.	14–52–12.5	
C-W (subtract)	2–48–35	
W.T. of L.A.N.	12–03–37.5	

Eq.T.	(—)	3–37.5
Cor.	(−)	1.0
Eq.T.	(−)	3–38.5
H.D.		1.2
Int.		.8
Cor.		1.0

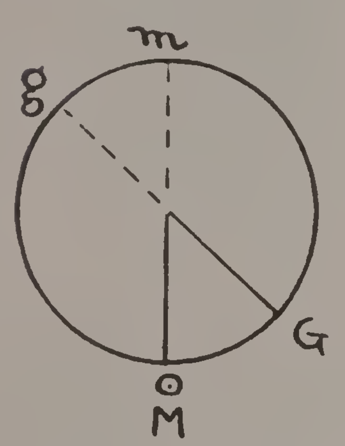
d		23–00.9	I.C. (−)	1–00
L		42–20	T. 46 (+)	9–39
L+d		65–20.9	Sub. (+)	0–18
H_a		24–39.1	Cor. (+)	8–57
Dec.		23–01.1 (S)	d	23–00–54
Cor.	(−)	0.2	d+c	23–09–51
d		23–00.9 (S)	K_n	66–50–09
H.D.	(−)	0.2	h_s	24–23–00
Int.		.9	Lat.	42–27–09 N.
Cor.	(−)	0.2		

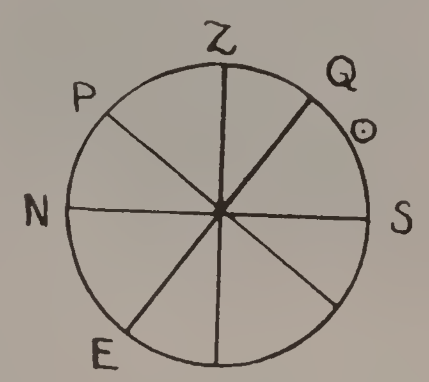
28. A constant may also be computed in advance of observation for a given interval before local apparent noon, using the method of the reduction to the meridian. In this case the reduction at^2 must be computed, finding a from the known approximate latitude and the declination. To avoid interpolation "t" is selected as an even number of minutes. The sextant altitude observed at the selected time, when applied to this constant gives the latitude at time of sight. The constant may be altered to give the noon latitude by applying the run in latitude for the interval to noon.

EXAMPLE: On 2 January, 1925, a navigator predicts the noon D.R. position to be Lat. 22°–15′–30″ N., Long. 44°–02′–18″ W. He decides to prepare a constant for use at 12 minutes before L.A.N. and obtains the following data: C-W 2–51–10, chro. slow 10^m–18^s, I.C. (+) 1′–00″, height of eye 42 feet. Find W.T. of L.A.N., W.T. of observation, and work out constant. At time of observation h_s is 44°–40′–15″. Find latitude at time of sight. If the vessel is on course 20° true, speed 10 knots, what was latitude at L.A.N.?

CONSTANT FOR REDUCTION TO THE MERIDIAN, SUN.

2 JAN., 1925, A.M. SUN.





Lat. 22°–15′–30″ N.

λ 44°–02′–18″ W.

= 2^h–56^m–$09^s.2$

$L = z - d = 90 - (h_s + c) - d$

$K_n = 90 - c - d$, $K_R = K_n - at^2$

$H_a = 90 - L - d = 90 - (L + d)$

L.A.T. of L.A.N.	12–00–00	L	22°–15′.5	I.C.	(+) 1–00		
λ (W.)	2–56–09.2	d	22 –55 .8	T. 46	(+) 8–46		
G.A.T. of L.A.N.	14–56–09.2 (2 Jan.)	L+d	45 – 11.3	Sub.	(+) 0–18	Eq.T.	(−) 4–05.8
Eq.T. (sign reversed)	(+) 4–06.9		90°–00′	Cor.	(+) 10–04	Cor.	(+) 1.1
G.C.T. of L.A.N.	15–00–16.1 (2 Jan.)	H_a	44°–48′.7	Dec.	22–56.0	Eq.T.	(−) 4–06.9
Chro. slow	(−) 10–18.0			Cor.	(−) 0.2	H.D.	1.2
Chro. T. of L.A.N.	14–49–58.1		90–00–00	d	22–55.8	Int.	.9
C-W (subtract)	2–51–10	d	22–55–48	H.D.	0.2	Cor.	1.08
W.T. of L.A.N.	11–58–48.1	90−d	67–04–12	Int.	1		
W.T. of Obs.	11–46–48	Cor.	(−) 10–04	Cor.	0.2		
t	12–00.1	K_n	66–54–08				
		at^2	5–46				
L=22.3 N. } a =2″.4		K_R	66–48–22				
d=22.9 S. } at^2=5′–46″		h_s	44–40–15				
		Lat.	22–08–07 N.				
C 20° Dist. 2 miles		Δ L	(+) 1–54 N.				
		Lat.	22–10–01 N.				

29. It is usual to combine both of the preceding methods, that is, the navigator computes in advance a series of constants one of which is to be used for the altitude at transit if obtained, and the others at certain intervals before transit. The intervals before noon are usually taken as a regular series, differing from each other by a uniform number of minutes, usually from two to five minutes. Having computed this series of constants the navigator begins to observe the sun's altitude shortly before the watch time for which the first constant has been computed. He takes the altitude of the sun at the watch time of the first constant and predicts the noon latitude. He then again observes the sextant altitude of the sun at the watch time of each of the other constants and at Local Apparent Noon, and applies these altitudes to the corresponding constants. The resulting latitudes in all cases should be about the same. Should any of the observations be lost, due to clouds, the result of the other observations give the navigator the noon latitude. The closeness with which the various results agree, gives a check on the accuracy of the observations and computations.

The following is quoted from Bowditch:

"A common practice at sea is to commence observing the altitude of the sun's lower limb above the sea horizon about 10 minutes before noon, and then, by moving the tangent-screw, to follow the sun as long as it rises; as soon as the highest altitude is reached, the sun begins to fall and the lower limb will appear to *dip*. When the sun dips the reading of the limb is taken, and this is regarded as the meridian observation.

"It will, however, be found more convenient, and frequently more accurate, for the observer to have his watch set for the local apparent time of the prospective noon longitude, or to know the error of the watch thereon, and to regard as the *meridian* altitude that one which is observed when the watch indicates noon. This will save time and try the patience less, for when the sun transits at a low altitude it may remain 'on a stand,' without appreciable decrease of altitude for several minutes after noon; moreover, this method contributes to accuracy, for when the conditions are such that the motion in altitude due to change of hour angle is a slow one, the motion therein due to change of the observer's latitude may be very material, and thus have considerable influence on the time of the sun's dipping. This error is large enough to take account of in a fast moving vessel making a course in which there is a good deal of northing or southing.

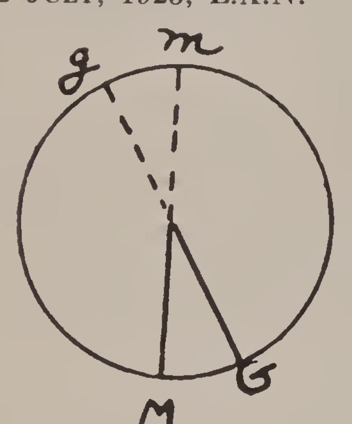
"In observing the altitude of any other heavenly body than the sun, the watch time of transit should previously be computed and the meridian altitude taken by time rather than by the dip. This is especially important with the moon, whose rapid motion in declination may introduce still another element of inaccuracy."

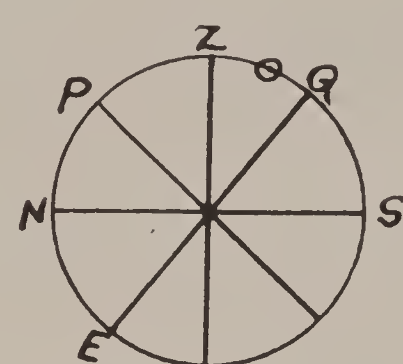
The method of accurately determining the noon D.R. longitude involves the determination of the sun's hour angle by observation at some time during the forenoon, and will be explained in a later chapter.

EXAMPLE: In the forenoon of 2 July, 1925, a ship is steaming at 15 knots on course 33° true. The navigator has predicted the position at local apparent noon to be, Lat. 38°–24′ N., Long. 24°–10′ W. He decides to prepare constants for use with reduction to the meridian of the sun, and to take observations every 4 minutes, beginning 12 minutes before L.A.N. Given the following data, find the W.T. of L.A.N., the time at which each observation for reduction to the meridian is to be taken, and the constants, taking account of the run in latitude from the time of observation to L.A.N. The I.C. of the sextant is (+) 1′–00″, height of eye 32 feet, chro. slow 1^m–01.7^s, C-W 2–14–17. If the sextant altitudes of the sun observed at 4 minute intervals before L.A.N. and at L.A.N. are 74°–18′–15″, 74°–24′–30″, 74°–27′–45″, and 74°–28′–30″, find the noon latitudes.

CONSTANT FOR A SERIES OF REDUCTIONS TO THE MERIDIAN.

2 JULY, 1925, L.A.N. SUN.





Lat. 38°–24′ N.

λ 24°–10′ W.

= 1^h 36^m–40^s

$L = d + z = d + 90 - H_o = d + 90 - (h_s + C)$

$K_n = d + 90 - C$. $H_a = d + 90 - L$.

L.A.T. of L.A.N.	12–00–00										90–00
λ (W.)	1–36–40								d		23–03.7
G.A.T. of L.A.N.	13–36–40	(2 July)	Eq.T.	(−)	3–44.9				90+d		113–03.7
Eq.T. (sign reversed)	(+) 3–45.7		Cor.	(+)	0.8				L		38–24
G.C.T. of L.A.N.	13–40–25.7	(2 July)	Eq.T.	(−)	3–45.7	Dec.		23–04.0 N.	H_a		74–39.7
Chro. slow	1–01.7		H.D.	(+)	0.5	Cor.	(−)	0.3	T. 46	(+)	10–12
Chro. at L.A.N.	13–39–24.0		Int.		1.6	d		23–03.7 N.	Sub.	(−)	0–14
C-W (subtract)	2–14- 17		Cor.	(+)	0.8	H.D.	(−)	0.2	I.C.	(+)	1–00
W.T. of L.A.N.	11–25–07					Int.		1.7	Cor.	(+)	10–58
						Cor.		.3			

L 38°–24′ N., d 23°–03′.7 N., a=5.3″

90+d	113–03–42	at^2	1–25		5–39		12–43
Cor.	(−) 10–58						
K_n	112–52–44	K_n	112–52–44	K_n	112–52–44	K_n	112–52–44
		K_4	112 -51–19	K_8	112 47–05	K_{12}	112–40–01
h_s	74–28–30	h_{s4}	74–27–45	h_{s8}	74–24–30	h_{s12}	74–18–15
Lat. at sight	38–24- 14 N.		38–23–34 N.		38–22–35 N.		38–21–46 N.
Course, 33°, Dist., 1, 2, 3, mi.		Δ L	0–48 N.		1–42 N.		2–30 N.
Lat. at L.A.N.	38–24–14 N.		38–24–22 N.		38–24–17 N.		38–24–16 N.

LATITUDE BY OBSERVATION OF POLARIS.

30. The latitude of a place is equal to the altitude of the elevated pole. Therefore if the north star, Polaris, were exactly at the north pole, its corrected observed altitude would be equal to the latitude, and in the northern hemisphere the latitude could be directly obtained by observing the altitude of Polaris. However, Polaris is not exactly at the north pole, its polar distance (in 1925) being about 1°–06′. It therefore moves about the pole, as do the other stars, in a diurnal circle, which,

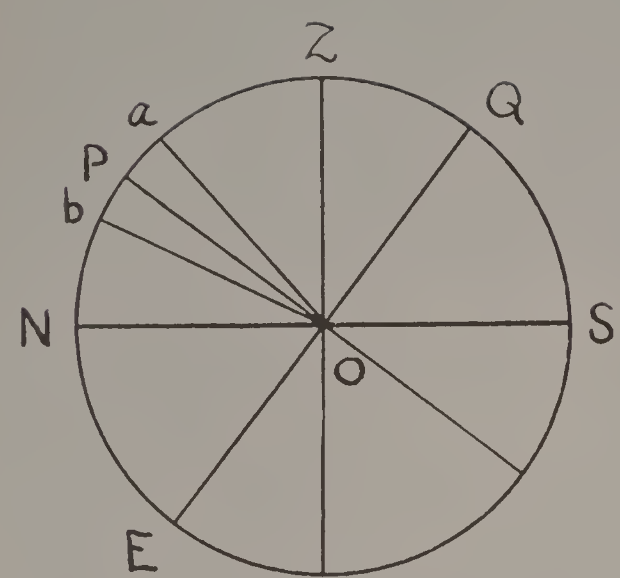


Fig. 3

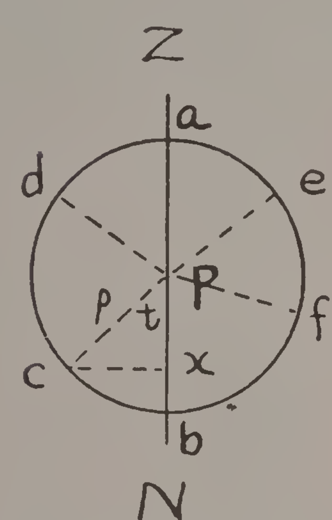


Fig. 4

however, is comparatively very small, and it transits the upper and lower branches of the meridian each sidereal day. Let Figure 3 represent the meridian of a place, and a and b the positions of Polaris at upper and lower transits. When the star is at a, the latitude is equal to the observed altitude, aON, minus the polar distance, aOP, and when the star is at b, the latitude is equal to the observed altitude plus the polar distance.

In Figure 4, let ZPN represent the meridian as seen from O, Figure 3, P the north pole, and c d e f the small diurnal circle of Polaris. Since the diurnal circle of Polaris is relatively small the following proof is approximately correct and gives results accurate enough for the practical navigator. If Polaris is at any position c, not on the meridian, its altitude will differ from the altitude of the elevated pole by xP. Let t be the hour angle of Polaris, p its polar distance. The n xP = p cos t. By the same method the difference between the altitude of the pole and of Polaris may be shown to be p cos t for any other position of Polaris, such as d, e, and f.

The values of p cos t have been computed for every ten minutes of the observer's local sidereal time and are tabulated in Table I of the Nautical Almanac, and may be determined for any other instants of L.S.T. by a simple interpolation. The tabulated values are accompanied by the proper sign for application to the observed altitude.

Example: At W.T. 6–32–15 a.m., 2 January, 1925, the navigator of the U.S.S. Mississippi in Lat. 30°–27′–16″ N., Long. 134°–18′–22″ W., observed the star Polaris for latitude as follows: C-W 8–51–12, chro. slow 6^m–02^s, I.C. (+) 2′–00″, height of eye 40 feet, h_s 29°–30′–15″. Find latitude.

W.T.	6–32–15	
C-W	8–51–12	
Chro.	15–23–27	
Chro. slow	6–02	
G.C.T.	15–29–29	(2 Jan.)
R.A.M.☉+12	6–44–27.0	
III	2–32.7	
G.S.T.	22–16–28.7	
Long.	8–57–13.5	W.
L.S.T.	13–19–15.2	

h_s		29–30–15
I.C.	+	2–00
		29–32–15
T. 46	(−)	7–55
H_o		29–24–20
Cor. Tab. I		1–05–30
Lat.		30–29–50

Given the data below find the W.T. of transit and the latitude by observation at transit.

	Problem 1	Problem 2	Problem 3	Problem 4
Body	Sun	Sun	Moon	Moon
Date	2 Jan., 1925	2 May, 1925	2 July, 1925	2 Jan., 1925
D.R. Lat.	33–08 S.	38–16 N.	50-01 N.	34–40 S.
D.R. Long.	45–17 W.	72–10–25 W.	167–00 E.	54–04–00 W.
C-W	3–03–09	4–52–16	1–56–04	3–26–42
Chro. error	slow 1^m–04.9^s	fast 3^m–54^s	fast 56^m–19^s	slow 32^m–17^s
I.C.	(−) 1′–00″	(+) 1′–30″	(+) 1′–30″	0–00
Ht. of eye	31 feet	40 feet	40 feet	36 feet
h_s	79–40–00	66–55–30	27–59–00 (lower limb)	50–09-30 (lower limb)
Answers:				
W.T. of Transit	12–01–01.1	11–57–15.9	8–17–07.1 p.m.	6–22–05 p.m.
Lat. at Transit	33–06-23 S.	38–15–35 N.	48–57–34 N.	34–37–14 S.

	Problem 5	Problem 6	Problem 7	Problem 8
Body	Denebola	Vega	Jupiter	Venus
Date	2 July, 1925	4 May, 1925	3 Oct., 1925	4 Oct., 1925
D.R. Lat.	27–36–45 S.	59–30–15 N.	39–48 N.	16–43 N.
D.R. Long.	82–15–12 E.	22–01–00 W.	74–38 W.	127–18 E.
C-W	6–25–38	1–12–32	4–36–17	3–55–58
Chro. error	fast 10^m–37.2^s	slow 12^m–18.4^s	slow 3^m–28^s	fast 24^m–18.3^s
I.C.	(+) 2′–30″	(−) 0′–45″	(−) 1′–00″	(−) 3′–00″
Ht. of eye	36 feet	32 feet	42 feet	46 feet
h_s	47–26–00	69–21–00	27–14–10	53–56–00

Answers:

W.T. of Transit	5–21–15.0	3–51–20.2	6–29–41.8	2–23–54.5 p.m.
Lat. at Transit	27–38–47 S.	59–28–16 N.	39–49–10 N.	16–41–29 N.

Given the data below find the latitude at time of sight.

	Problem 1	Problem 2	Problem 3	Problem 4
Body	Sirius	Denebola	Venus	Saturn
Date	2 Oct., 1925	3 Jan., 1925	2 Oct., 1925	3 July, 1925
D.R. Lat.	45–15 N.	10–00 S.	26–17 N.	35–03 N.
D.R. Long.	64–20–30 W.	124–30–45 E.	30–15–00 W.	45–06 W.
Watch	5–50–00 a.m.	5–32–00 a.m.	2–20–00 p.m.	7–35–00 p.m.
C-W	4–20–53	3–05–10	2–02–10	3–00–15
Chro. error	fast 03^m–55^s	fast 03^m–32^s	fast 01^m–10^s	slow 00^m–08^s
I.C.	(−) 2′–00″	(−) 1′–00″	(+) 1′–00″	(+) 1′–30″
Ht. of eye	46 feet	48 feet	36 feet	40 feet
h_s	28–20–00	65–00–00	44–45–00	43–15–00

Answers:

Latitude	54–11–21 N.	10–06–27 S.	26–22–16 N.	35–05–30 N.

	Problem 5	Problem 6
Body	Moon (lower limb)	Moon (upper limb)
Date	2 Jan., 1925	2 July, 1925
D.R. Lat.	28–30 S.	49–32 N.
D.R. Long.	47–00 W.	167–00 E.
Watch	6–50–00 p.m.	8–10–00 p.m.
C-W	2–58–21	1–56–04
Chro. error	fast 00^m–40^s	fast 56^m–19^s
I.C.	0′–00″	(−) 0′–30″
Ht. of eye	40 feet	50 feet
h^s	56–30–00 (lower limb)	28–01–00 (upper limb)

Answers:

Latitude	28–26–51 S.	49–30–40 N.

Given the data below find the noon constant; thence the constant for use with a reduction to the meridian taken at the indicated watch time. The h_s given is taken at the indicated watch time. Find latitude at time of sight.

	Problem 1	Problem 2	Problem 3	Problem 4
Date	1 May, 1925	4 Oct., 1925	3 Jan., 1925	3 May, 1925
D.R. Lat.	35–18–00 S.	51–43–20 N.	28–30–20 S.	46–34–00 N.
D.R. Long.	29–53–00 E.	148–36–00 E.	124–30–45 E.	31–27–30 W.
Watch	11–48–53	11–30–30.5	12–40–40.8	11–46–58.2
C-W	10–00–59	1–59–06	3–05–10	2–11–11
Chro. error	fast 2^m–18.4^s	slow 6^m–27^s	fast 03^m–32^s	fast 5^m–29^s
I.C.	(−) 2′–15″	0′–00″	(−) 1′–20″	(−) 00′–30″
Ht. of eye	24 feet	37 feet	27 feet	26 feet
h_s	39–29–30	34–00–00	84–20–00	58–59–12
Answers:				
Constant	Kn = 74–53–32	Kn = 85–45–54	Kn = 112–43–01	Kn = 105–27–45
	Kr = 74–50–12	Kr = 85–37–21	Kr = 112–38–37	Kr = 105–23–35
Latitude	35–20–42 S.	51–37–21 N.	28–18–37 S.	46–24–23 N.

	Problem 5	Problem 6
Date	1 July, 1925	1 Jan., 1925
D.R. Lat.	12–25–00 N.	15–01–00 S.
D.R. Long.	59–20–04.5 W.	74–56–15 E.
Watch	11–55–21.6	12–00–00.2
C-W	3–56–04	6–59–23
Chro. error	fast 0^m–30^s	slow 0^m–21^s
I.C.	(+) 1′–00″	(+) 0′–45″
Ht. of eye	42 feet	28 feet
h_s	78–51–25	81–48–00
Answers:		
Constant	Kn (−) 66–42–20	Kn (−) 66–45–44
	Kr (−) 66–26–20	Kr (−) 66–42–24
Latitude	12–25–05 N.	15–05–36 S.

CHAPTER III.

AZIMUTH.

31. The azimuth of a body is the arc of the horizon intercepted between the north point of the horizon and the vertical circle passing through the body. It is measured from the north point clockwise through 360°. It may also be defined as the angle at the zenith intercepted between the north branch of the observer's meridian and the vertical circle through the body. Azimuth is simply another name for true bearing. The north point of a compass without error coincides in direction with the north point of the horizon. The compass is graduated to agree with the measurement of azimuth from 0° to 360°, clockwise. As the compass is so constructed that its card lays horizontal, *i. e.*, parallel to the plane of the horizon, a bearing of a body taken with a compass without error is the same as the body's azimuth. The determination of the azimuth of a celestial body is an operation of frequent necessity. At sea the comparison of a true bearing with a bearing as observed by compass affords the only method of determining the compass error.

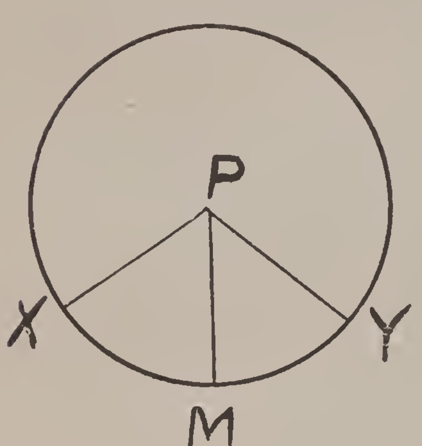


FIG. 1.

The meridian angle of a body is the smaller angle at the pole between the observer's meridian and the circle of declination passing through the body, measured east or west, according as the body is east or west of the meridian, in time units, through 12 hours. If the body is west of the meridian it is the same angle as the body's hour angle. If the body is east of the meridian it is equal to 24 hours minus the body's hour angle. In the figure, a projection on the plane of the equinoctial, MPX is the meridian angle, and also the hour angle, of a body X. MPY is the meridian angle of a body, Y, $=24^h$—H.A. The standard symbol for a meridian angle is "t."

When the observer's latitude (L), the body's meridian angle, t, and the body's declination (d) are known, the azimuth of a body may be computed. As the computation is too laborious for the navigator to perform every time he requires an azimuth, suitable tables, called azimuth tables, have been computed and are published by the Hydrographic Office. In these tables the values of the azimuth are tabulated for the various probable combinations of L and d, in whole degrees, for every 10 minutes of the value of t.

COMPUTATION OF THE AZIMUTH OF A BODY.

32. Let the following be known: t, the meridian angle of the body, d, the body's declination, L, the observer's latitude. In the accompanying figure let PZA be the projection of the astronomical triangle on the plane of the horizon, with NS as the projection of the meridian, P the elevated pole, Z the zenith, and A the position of a body west of the meridian. The sides PA and PZ and the meridian angle t, are known. Call the angle PZA, Z, call the angle PAZ, A. Two sides and the included angle of the astrononmical triangle being known it may be solved for Z, for from Napier's analogies,

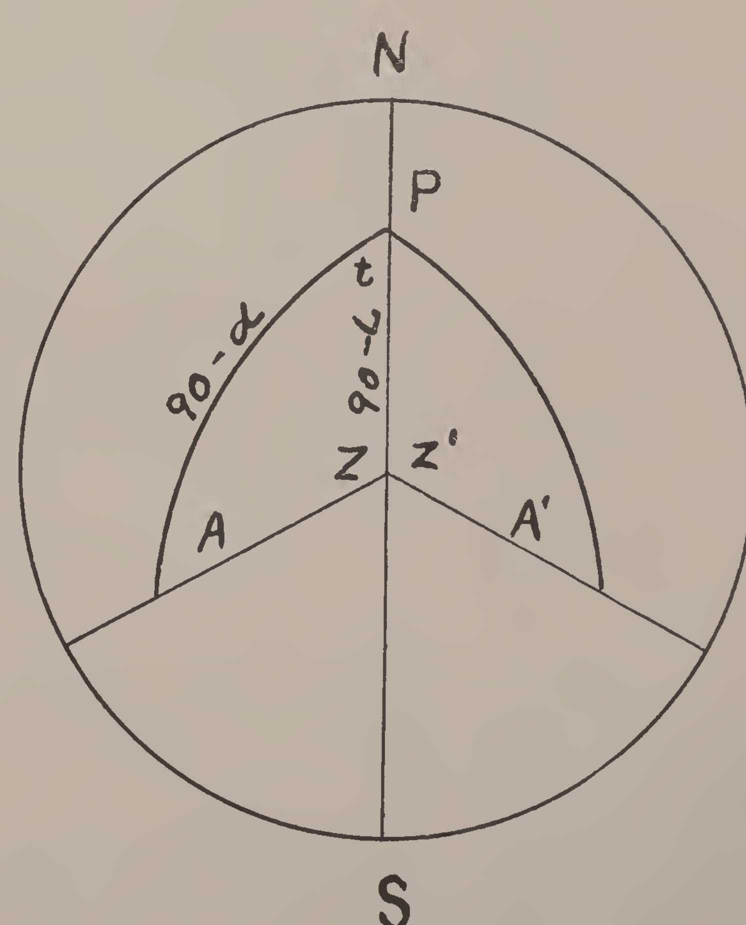


FIG. 2.

$$\tan \tfrac{1}{2}(Z-A) = \cot \tfrac{1}{2} t \sin \tfrac{1}{2}(L-d) \sec \tfrac{1}{2}(L+d)$$
$$\tan \tfrac{1}{2}(Z+A) = \cot \tfrac{1}{2} t \cos \tfrac{1}{2}(L-d) \operatorname{cosec} \tfrac{1}{2}(L+d)$$

Solving for $\frac{1}{2}(Z-A)$ and $\frac{1}{2}(Z+A)$, and adding the results, we have Z. Let Z_n = the body's azimuth. Then, by inspection,

$$Z_n = 360° - Z.$$

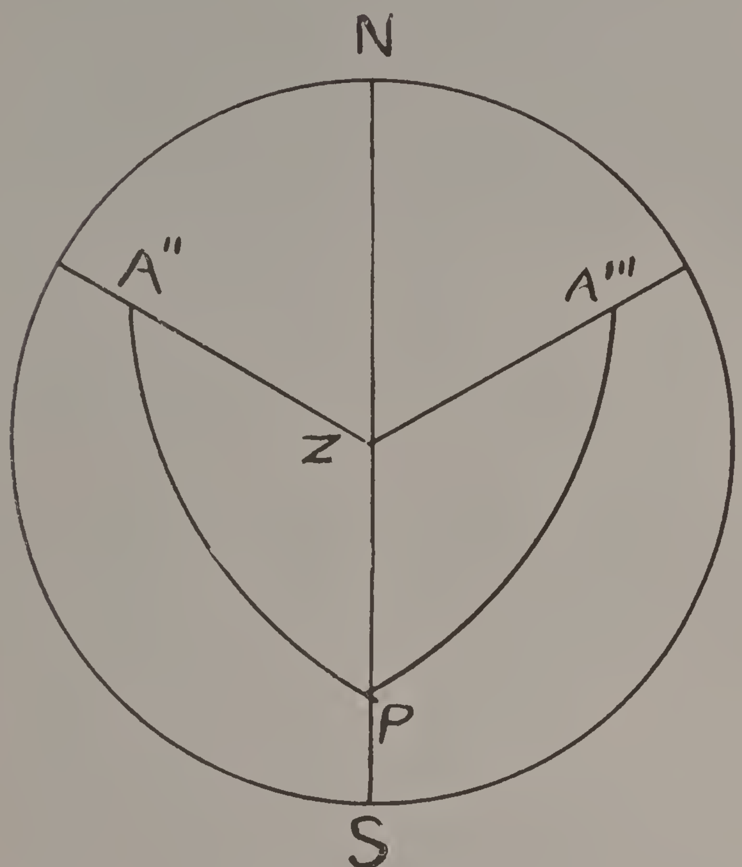


FIG. 3.

Let the body be east of the meridian, in position A'.

The solution is as before, except that the result of the solution is Z', which in this case, is the body's true azimuth, Z_n.

If the observer is in south latitude, *i. e.*, if the south pole is the elevated pole, the figure becomes as shown, (Fig. 3). The solution is as before, but if the body is west of the meridian (at A'') then Z is measured from south to west, and $Z_n = 180° + Z$.

If the body is east of the meridian at (A'''), then Z is measured from south to east, and $Z_n = 180° - Z$.

The Azimuth Tables are computed and results tabulated for the above four cases, and cover all the probable combinations of latitude and declination with each ten minutes of the value of t. Hence in entering those tables use L, d, and t, as arguments.

EXPLANATION OF THE RED AZIMUTH TABLES.

33. Hydrographic Office Publication 71, known as the Red Azimuth Tables, was computed primarily for use with the sun, but must also be used for other bodies whose declinations are less than 23°. Separate pages are provided for each degree of the value of L from 0° to 70°. For convenience in working with the sun the tables are arranged with the argument t expressed as apparent time. In the right hand column of the page t appears under the caption "Apparent Time, P.M.", and in the left column under "Apparent Time, A.M." The left hand column is not available for use with other bodies than the sun. It is therefore better practice to disregard the left hand column; to always work with the right hand column, and to consider that column as under the heading "Meridian Angle, t."

In Figures 2 and 3, the value of the side AP is shown as 90—d. If the declination is south when the latitude is north, and vice versa, then the sign of d becomes (—). The value of the side AP then becomes $90-(-d) = 90+d$. To provide for this the Red Azimuth Tables are divided into two parts, the pages of which are headed: "Declination Same Name as Latitude," and "Declination Contrary Name to Latitude."

The values of Z are tabulated against t and d. These values of Z must be converted to Z_n, according to the proof above.

USE OF THE RED AZIMUTH TABLES.

1. Compute the meridian angle, t.
2. Enter the tables in the proper part, according as the latitude and declination are of the same or different names, and select the page headed with the value of the latitude.
3. Select the declination column headed with the value of d. In this column select the value of Z tabulated against the value of t.
4. In north latitude $Z_n = Z$, if the body is east of the meridian, and $360° - Z$ if the body is west of the meridian. In south latitude $Z_n = 180° - Z$ if the body is east of the meridian, and $180° + Z$ if the body is west of the meridian.

4. (Alternative) Mark Z according to the rule at the bottom of the page, substituting "when the body is east of the meridian" for "when the time is a. m." and "the body is west of the meridian" for "when the time is p. m." Then convert Z to Z_n.

4. (2nd Alternative) Remembering that in north latitude the tabulated values of Z are measured from the north point, and in south latitude from the south point, and to the east or west according as the body is east or west, draw a rough projection on the plane of the horizon and compute Z_n.

EXPLANATION OF THE BLUE AZIMUTH TABLES.

(Hydrographic Office Publication No. 120.)

34. These tables are computed and tabulated in the same manner as that described for the Red Tables, except that:

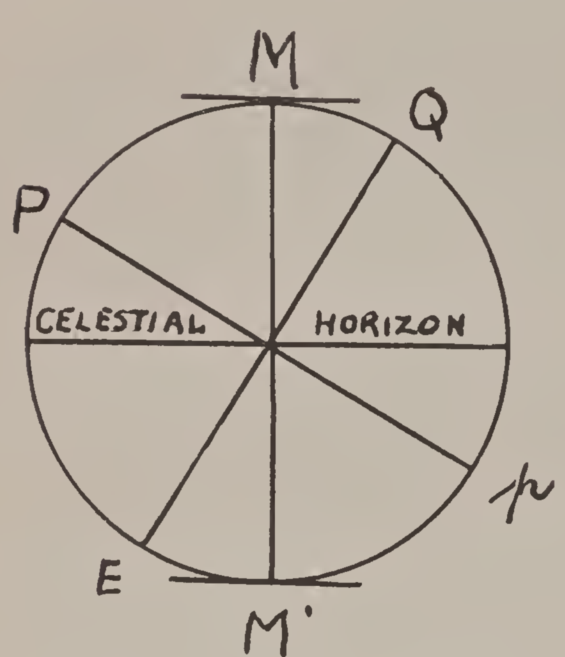


Fig. 4.

1. The values of Z are tabulated for values of d from 24° to 70°, and hence are not used with the sun. Therefore the columns for t as an argument are not headed "Local Apparent Time" but simply "Hour Angle." The latter, however, is incorrect, and should be considered to be "Meridian Angle, t."

2. The tables are computed for latitudes and declinations of the same name only, but are available for use with latitudes and declinations of different names. To understand this consider the following:

Two places, M and M′, 180° apart on the same meridian, one in north latitude and the other in the same latitude, south, will have the same celestial horizon (see Figure 4). Let Figure 5 be a projection on the plane of that horizon, and P be the north pole. Then Z is the computed azimuth of a given body, X for the place in north latitude. The computed azimuth of the same body for the place in south latitude is measured from the south point of the horizon and is therefore SZX, the supplement of Z.

Suppose you have a latitude and a declination of different names to work with. Assume yourself shifted 180° in latitude on the same meridian. Your celestial horizon will be the same as before, your latitude will be numerically the same, but your latitude and declination will now be of the same name. However, the meridian angle of the body will now be measured from what was before the lower branch of the meridian, *i. e.*, it will be the supplement of the meridian angle computed for your true position. With this supplementary meridian angle select the value of the computed azimuth. Call this Z′. This will be the supplement of Z, the computed azimuth for your true position. Therefore, Z = 180—Z′.

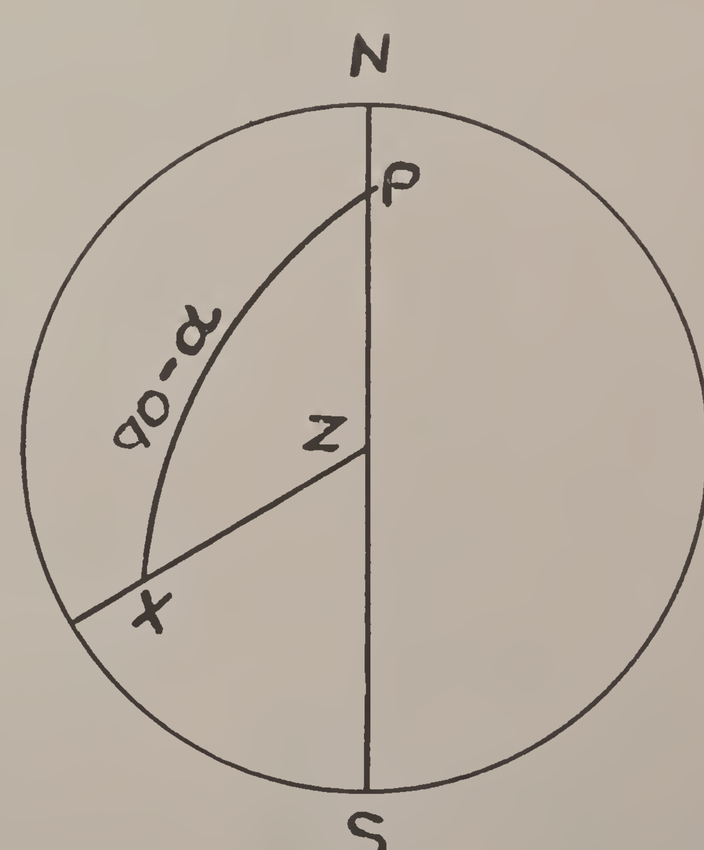


Fig. 5.

USE OF THE BLUE AZIMUTH TABLES.

1. If the latitude and declination are of the same name.
   (a) Compute the meridian angle t, and mark it E or W.
   (b) Select the page for given latitude.
   (c) In the column for the given declination select the tabulated value of Z against the value of t.
   (d) Mark Z according to the rule at the bottom of the page and convert to Z_n.
2. If the latitude and declination are of different names.
   (a) Compute the meridian angle t, mark it E or W, and find its supplement t′.
   (b) Select the page for the given latitude.
   (c) In the column for the given declination select the tabulated value of Z′ against the value of t′.
   (d) Find the supplement to Z′=Z. Mark it according to the rules at the bottom of the page, and convert to Z_n.

INTERPOLATING IN THE AZIMUTH TABLES.

35. The values of Z may be selected from the Azimuth Tables without interpolation only when the values of L and d are in whole degrees and the value of "t" ends in an even ten minutes. For other cases resort must be had to interpolation. To interpolate: Select the value of Z for the next lower whole degree of latitude and declination and the next lower 10 minutes of the tabulated value of "t." Call this value of Z the base.

Then keeping L and d as before, select the value of Z for the next higher tabulated value of "t." The difference between this and the base is the difference caused by a ten minute change of "t." Find the difference for 1 minute, and multiply by the difference in the number of minutes in the given value of t, and "t" as used for the base.

Next, using the values of t and L as used in the base, select the value of Z for the value of d one degree greater than used in the base. The difference between this value of Z and the base is the difference for one degree change of declination. Multiply by the difference in the value of d as given and as used in the base, expressed to the nearest tenth of a degree.

Repeat the operation for the latitude.

Find the algebraic sum of all the corrections and apply to the base.

Red Tables. Latitude and Declination, Same Name. *t* West.

Example: At about 6:03 p.m., 2 January, 1925, in Lat. 19°–30′S., Long. 61°–05′ E., the navigator observes the sun for deviation of standard compass as follows: W 6–03–21, C-W 8—00—26, Chro. fast 1^m–01.2^s, Z (p.s.c.) 260°, variation from chart 10°–00 W. Find the deviation.

W	6–03–21	
C-W	8–00–26	
C. T.	14–03–47	
Chro. fast	1–01.2	
G.C.T.	14–02–45.8	(2 Jan.) ⊙'s dec. = 22°–56′ S.
Eq. T.	(—) 4–05.8	
G.A.T.	13–58–40.0	
Long. E.	4–04–20.0	
L.A.T.	18–03–00	
t (W)	6–03–00	

		t	d	L		
Base		69–06	69–06	69–06		69–06
t	6–03	68–22	68–08	69–13	Cor.	(−) 1–01
d	22°.9	(−) 44	(−) 58	(+) 07	Z	S 68–05 W.
L	19°.5	4.4	(−) 52.2	(+) 3.5	Z_n	248–05
		(−) 13.2	(−) 13		Z (psc)	260–00
			+ 4		C.E.	11–55 W.
			Cor. (—) 1–01		Var.	10–00 W.
					Dev.	1–55 W.

Red Tables. Latitude and Declination, Same Name. *t* East.

Example: At about 7:30 a.m., 2 May, 1925, in Lat. 38°–08′ N., Long. 147°-03′ W., the navigator observes the sun to determine the deviation of the standard compass, as follows: W 7–28–37, C-W 9–33–54, Chro. slow 3^m–07.1^s, Z(p.s.c.) 76°–30′, variation from chart 17° E. Find the deviation.

W	7–28–37	
C-W	9–33–54	
C.T.	17–02–31	
Chro. slow	3–07.1	
G.C.T.	17–05–38.1	(2 May) ⊙'s dec. = 15°–22.1′ N.
Eq. T.	(+) 3–03.9	
G.A.T.	17–08–42.0	
Long. W.	9–48–12	
L.A.T.	7–20–30	
t	=4–39–30 E.	

		t	d	L		
Base		91–31	91–31	91–31		91–31
t	4–39.5	89–58	90–36	92–01	Cor.	(–) 1–47
d	15.4°	(–) 1–33	(–) 0–55	(+) 30	Z =	N 89–44 E.
L	38.1	9.3	.4	.1	Z_n	89–44
		9.5	(–) 22.0	(+) 3.0	Z (psc)	76–30
		465				
		837	(–) 88			
		(–) 88.35	110.0		C.E.	13–14 E.
			(+) 3			
			Cor. (–)107′=(–)1°–47′.		Var.	17–00 E.
					Dev.	3–46 W.

Red Tables. Latitude and Declination, Different Names. *t* East.

Example: At about 7:28 a.m., 3 October, 1925, Lat. 8°–33′ N., Long. 162°–10′ W., the sun is observed for deviation of standard compass as follows: W 7–28–03, C-W 10–37–40, Chro. slow 2^m–00.^{s}6, Z(p.s.c.) 81°, variation from chart 9°–30′ E.

W	7–28–03	
C-W	10–37–40	
C	18–05–43	
Chro. slow	2–00.6	
G.C.T.	18–07–43.6	(3 Oct.) ⊙'s dec. 3°–57.7′ S.
Eq. T.	(+)10-56.3	
G.A.T.	18–18–39.9	
Long. W.	10–48–40	
L.A.T.	7–29–59.9	
t	=4–30–00.1(E)	

		t	d	L		
Base		97–33	97–33	97–33		97–33
t	4–30			97–57	Cor. +	14
d	4° N.			+ 24	Z	N 97–47 E.
L	8°.6 S.					
				.6	Z_n	97–47
				Cor. (+) 14.4	Z(p.s.c.)	81–00
					C.E.	16–47 E.
					Var.	9–30 E.
					Dev.	7–17 E.

Red Tables. Latitude and Declination Different Name. *t* East.

Example: 2 October, 1925, at about 4:00 a.m., in Lat. 10°–49′ N., Long. 60°–11′–45″ E., observed the star α Canis Majoris, Sirius, for deviation of standard compass, as follows: W 3–58–02, C-W 7–59–30 Chro. fast 1^m–59^s, Z(p.s.c.) 133°–00′, variation from chart 0. Find the deviation.

W	3–58–02		
C-W	7–59–30		
C.T.	11–57–32		
Chro. fast	1–59		
G.C.T.	25–55–33	(1 Oct.)	
R.A.M.S.+12	0–36–49.8		
Table III	3–55.8		Dec. = 16°–36.7′ S.
G.S.T.	00–36–18.6		
Long. E.	4–00–47		
L.S.T.	4–37–05.6		
☆'s R.A.	6–41–51.6		
t (−)	2–04–46.0 E.		

		t	d	L		
Base		130–53	130–53	130–53		130–53
t	2–04.8	128–36	132–05	131–47	Cor. (+)	20
d	16.6 S.					
		(−) 2–17	(+) 1–12	(+) 54	Z	N 131–13 E.
L	10.8 N.	137	–72	.8	Z_n	131–13
		4.8	.6	+ 43.5		
		1096	+43.2	+43.2	Z(p.s.c.)	133–00
		548		+86		
		65.76		−66	C.E.	1°–47′ W.
		(−) 66		Cor. (+) 20	Var.	0–00
					Dev.	1°–47′ W.

Blue Tables. Two Cases, Latitude and Declination of the Same Name, and Latitude and Declination of Different Name.

Example: 2 July, 1925, p.m., in Lat. 31–06 S., Long. 29–53–00 W., the navigator observes the star α Scorpii (Antares) and the star B. Gemin. (Pollux) for the deviation of the compass as follows: W 6–28–13, C-W 2–04–00, Chro. slow 1^m–19^s, Z(p.s.c.) for Antares 114°; for Pollux 315°–30′. Variation from chart 20° W.

W	6–28–13		
C-W	2–04–00		
C.T.	8–32–13		
Chro. slow	+ 1–19		
G.C.T.	20–33–32	(2 July)	
R.A.M.S.+12	18–38–03.4		
Table III	3–22.7		
G.S.T.	15–14–58.1		
Long. W.	1–59–32.0		
L.S.T.	13–15–26.1		
☆'s R.A.	16–24–50.5	Dec. = 26°–16′ S.	
t (−)	3-09–24.4 E.		

		t	d	L		
Base		85–39	85–39	85–39		85–39
t	3–09.6	84–34	84–08	86–51	Cor. (−)	1–22
d	26.3° S. (−)	1–05	(−) 1–31	(+) 1–12	Z	S 84–17 E.
L	31.1 S.	65	91	72	Z_n	95–43
		9.6	.3	.1	Z (p.s.c.)	114–00
		390	(−) 27.3	+ 7.2	C.E.	18–17
		585	(−) 1–02		Var.	20–00 W.
		62.40	(+) 7.2		Dev.	1°–43′ E.
	(−) = 1′–02″		(−) 1–22			

Pollux:

L.S.T.	13–15–26.1	
☆'s R.A.	7–40–43	Dec. 28°–12.5′ N.
t	5–34–43.1 W.	
Supplement	6–25–16.9	

		t	d	L		
Base		63–20	63–20	63–20		63–20
t	6–25.3	62–12	62–26	63–39	Cor. (−)	46
d	28.2 N. (−)	1–08	(—) 54	(+) 9	Z	N 62–34 W.
L	31.1 S.	6.8	.2	.1	Z	S 117–26 W.
		5.3	(−) 10.8	.9	Z_n	297–26
		204	(−) 36		Z (p.s.c.)	315–30
		340	+ 0.9			
		(−) 36.04	− 46		C.E.	18–04 W.
					Var.	20–00 W.
					Dev.	1–56 E.

Given the data below find the true azimuth.

	Problem 1	Problem 2	Problem 3	Problem 4
Body	Sun	Sun	Vega	Antares
Date	3 Jan., 1925	2 Jan., 1925	3 Jan., 1925	1 May, 1925
Latitude	36–30–00 S.	24–18–30 N.	1–12–00 S.	30–42–00 S.
Longitude	123–15–30 W.	62–45–15 E.	123–15–30 W.	47–35–30 W.
Watch	8–35–16 a.m.	4–27–52 p.m.	8–35–16 a.m.	4–31–59 a.m.
C-W	8–14–38	7–16–48	8–14–38	3–38–16
Chro. Error	slow 08^m–41^s	fast 06^m28^s	slow 08^m41_s	fast 01^m–09^s
Answers:	Z_n 86–33	Z_n 233–36	Z_n313–02	Z_n 263–57

	Problem 5	Problem 6	Problem 7
Body	Vega	Sun	Sun
Date	2 July, 1925	4 Oct., 1925	3 Oct., 1925
Latitude	0–23 ′N.	7–45–15 S.	0–00
Longitude	107–36–45 E.	153–18–00 E.	107–36–45 E.
Watch	5–37–18 a.m.	7–53–12 a. m.	8–01–15 a.m.
C-W	4–41–52	1–42–36	4–41–52
Chro. Error	slow 08^m–37^s	fast 2^m–13^s	slow 08^m–37^s
Answers:	308–47	90–10	85-06

Given t, d, and L, to find Z_n for 23°–24° Declination.

t	d	L
3–33–58.1 E.	23–26.5 S.	35–26 N.

Answer: Z_n 131°–03′ (East).

CHAPTER IV.

LINES OF POSITION.

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36. A fix is an accurate determination of latitude and longitude.

A line of position is the locus of the possible positions of a ship. Thus, if the true bearing of a lighthouse from a ship is known, that bearing becomes a line of position. Again if the latitude has been obtained by the methods previously explained, a line may be drawn on the chart, running east and west in that latitude and extending through the probable longitudes. Such a line becomes a line of position.

A line of position is not a fix, but if two lines of position are determined, their intersection is a fix. Thus, if a line of position obtained by a bearing of a known navigational point, such as a light-house, can be crossed with a line obtained at the same time by a bearing of another navigational point, the intersection of the two lines is a fix.

A line of position obtained at one time may be used at a subsequent time if it is moved parallel to itself a distance equal to the run of the ship in the interim and in the direction of the run. Such a line of position is less accurate than a new line, because the amount and direction of its movement must be determined by the usual dead reckoning methods, and are subject to the errors of current, bad steering, and poor estimate of speed. Nevertheless, if two new lines cannot be obtained and crossed to obtain a fix, the fix obtained by a new line and an old line advanced is the most accurate that can be had. Of course the accuracy of such a fix will be effected by the accuracy with which the run of the ship has been reckoned. In practice a navigator may use a very old line in this way, for, from his experience, he may be sure that his reckoning of the run is very close. However, in the following pages it will be arbitrarily assumed that a line should not be advanced more than five hours.

As has been stated a line of position may be obtained in celo-navigation by means of a sight for latitude. However, it is more often obtained by means of a different type of observation. This latter method involves:

(a) The ability to determine the altitude and azimuth of a given celestial body, for a given point on the earth, at a given time.

(b) A knowledge of the principles of circles of equal altitudes.

COMPUTATION OF ALTITUDES.

37. For a given point on the earth let $L=$ the latitude, and $\lambda=$ the longitude. For a given instant of time let (d) be the declination of a body whose altitude is to be computed for that instant. Then, the civil or sidereal time of the instant and the longitude of the place being known, the meridian angle (t) of the body may be computed. The zenith distance (z) of the body and thence its altitude (H_c) may be computed from the formulæ:

(1) $\text{hav } z = \text{hav } t \cos L \cos d + \text{hav } (L \sim d)$

(2) $H_c = 90 - z$

The projection on the plane of the horizon of two astronomical triangles is shown in Figure 1, to illustrate the relation of the functions in formula (1) above.

A and B represent bodies west and east of the meridian respectively. It will be seen that for "A" the function (t) is the hour angle, while for "B" the value of (t) is 24 hours—H.A. = the meridian angle. However, since the haversine of 24^h—H.A. has the same value as the haversine of the H.A. the latter may always be used in the formula whether the body is east or west of the meridian. Therefore, either the hour angle or the meridian angle may be used in the equation for the value of t. Since, however, the meridian angle will be required for the determination of the azimuth, it is best always to determine the meridian angle, which is then available for the determination of both the computed altitude and the azimuth.

In Figure 1, the declination of A is shown as of the same name as the latitude, and the declination of B is of the different name. The polar distance of A is therefore 90—d, and of B is 90+d. The last term of formula (1) is the haversine of the difference between sides of the astronomical triangle formed by the polar distance and the co-latitude. For A this becomes (90—d)—(90—L) = L—d. For B it becomes (90+d)—(90—L) = L+d. Hence in computing the altitudes, use the haversine of the difference between the latitude and declination if they are of the same name, and of the sum if they are of different names.

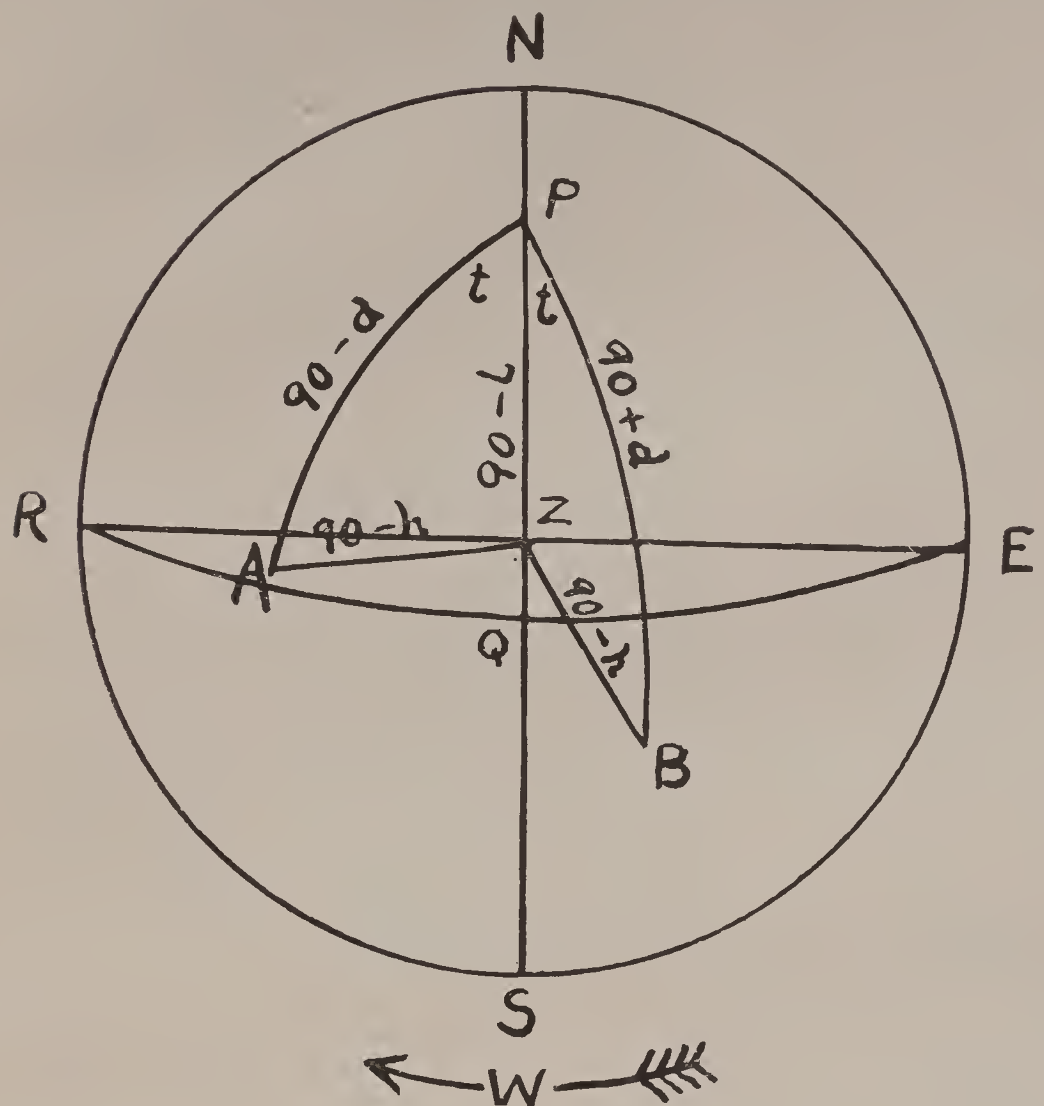


Fig. 1.

It should be noted that a computed altitude is a geocentric altitude, *i. e.*, the altitude as it would be observed at the center of the earth with an horizon parallel to the observer's horizon on the surface.

CIRCLES OF EQUAL ALTITUDES.

38. When a sextant altitude is corrected to make it available for use in the solution of the astronomical triangle, one of the corrections applied is that for parallax. The effect of this correction is to make the corrected altitude a geocentric altitude. A geocentric altitude may be defined as the altitude which a body would have if it were at an infinite distance from the earth. This is shown in Figure 2.

Let C represent any celestial body, A, the position of an observer on the earth, the circle a vertical circle of the earth in the same plane as C. Then H′R′ is the observer's terrestial horizon, and HR is his celestial horizon. C′A is drawn parallel to CO. Then CAH′ is the altitude of C as observed at A. ACO is the parallax of C = CAC′. This parallax is added to the altitude CAH′, giving the corrected altitude C′AH′. This is the same altitude which would be observed if the body were at an infinite distance.

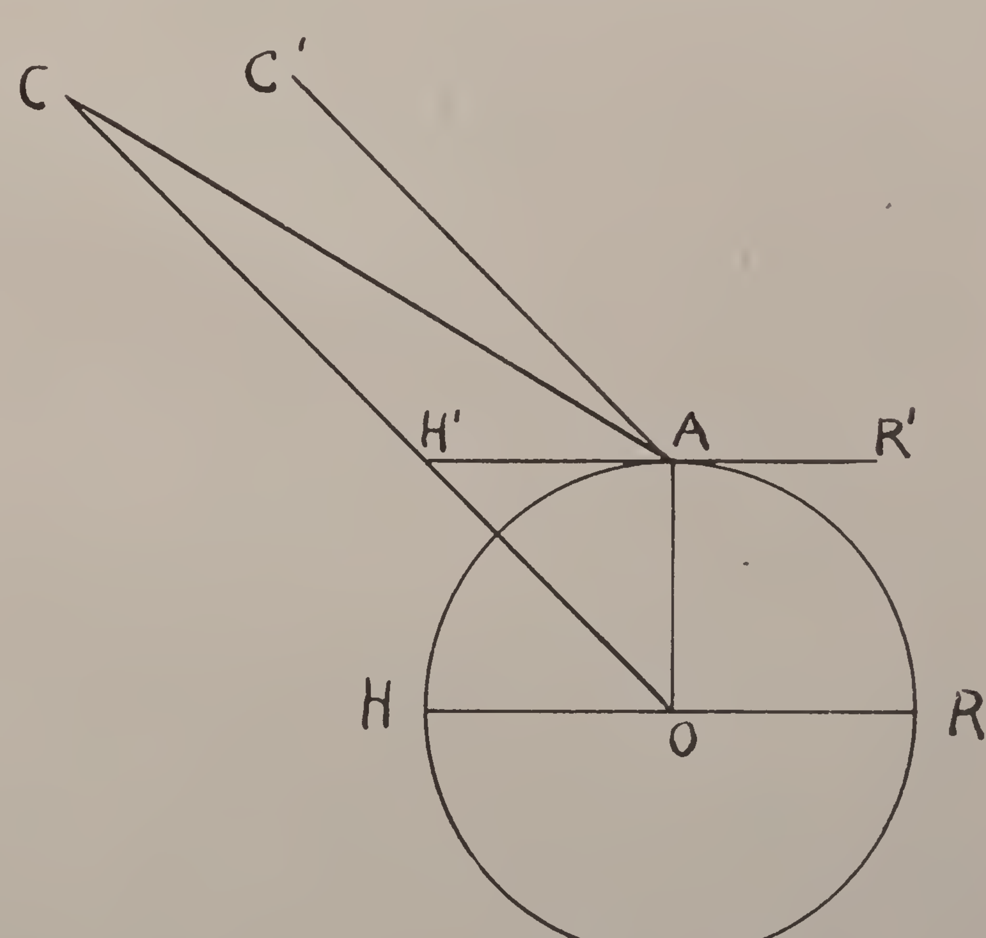


Fig. 2.

In the following discussions and figures, the altitude used will be the altitude as corrected for parallax, that is, it will be considered that the direction from the body to the observer is the same as that from the body to the center of the earth.

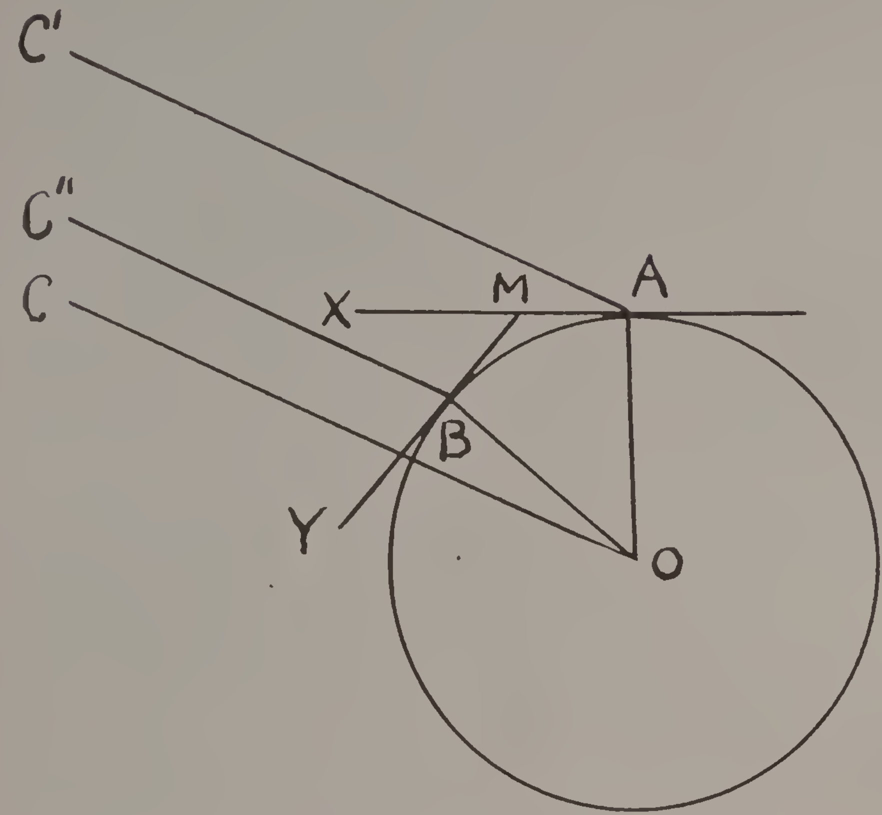


FIG. 3.

In Figure 3, let B be the position of another observer on the same vertical circle as A, and let OC be the direction from the center of the earth of any celestial body lying in the vertical circle BA. C″B and C′A are drawn parallel to CO. Then at this instant the corrected altitudes of C from A and B will be C′AX and C″BY, respectively. These altitudes, being the angles intercepted between parallel lines, by the horizons of A and B, differ by the amount of inclination of the horizons at A and B to each other =XMB=AOB. The angle AOB is measured by the arc AB, a part of a great circle of the earth. Therefore, since 1′ of arc of a great circle of the earth is equal to 1 mile, the corrected altitudes at A and B will differ in minutes by the number of miles between A and B.

Figure 4 is constructed in the same manner as Figure 2. Suppose the figure to rotate about the line CO. Then A will describe a circle whose trace is AA′. The line HA will describe a cone, AHA′. C′A will describe a cylinder. Then everywhere on the circle AA′ the altitude of C will be C′AH. Such a circle is called a circle of equal altitudes.

DEFINITION: For any body, a circle of equal altitude is a circle of the earth cut by a plane perpendicular to the line joining that body to the earth's center.

For a given instant there is a series of circles of equal altitudes for any body.

Five such circles are shown in Figure 5.

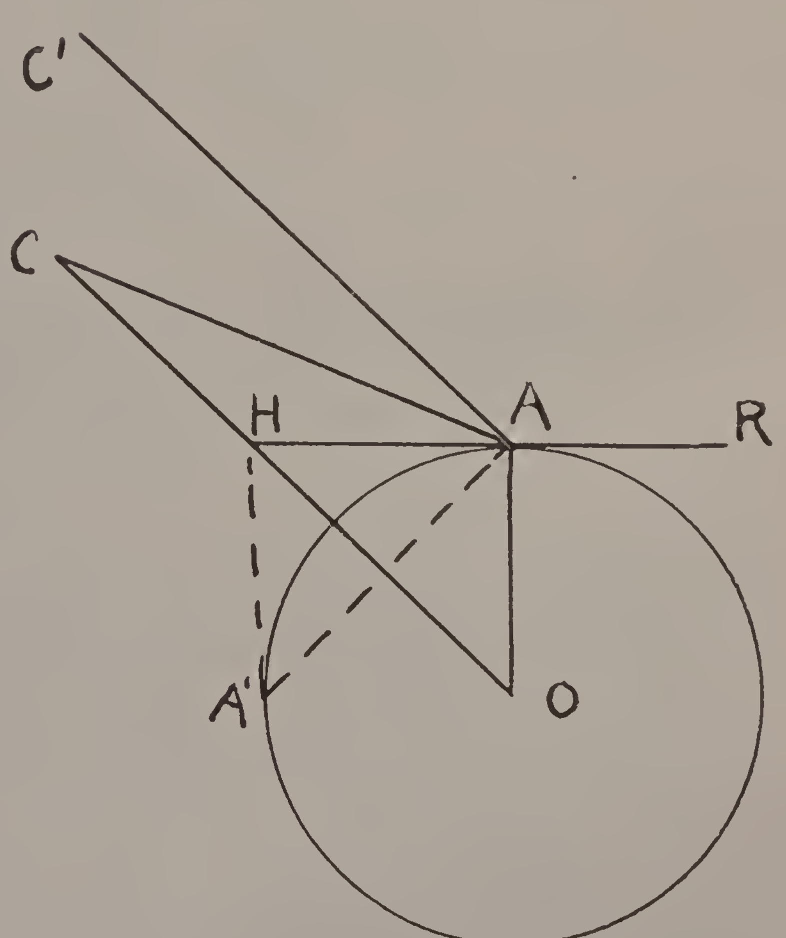


FIG. 4.

All of these circles have their center on the line SO. They are therefore parallel circles. The radius of the circle EE′, on which circle the altitude will be zero, will be OE, the radius of the earth. The radius of the circle AA′, on which circle the altitude is 86°, is roughly 280 miles. The radii of all intermediate circles will be between 4000 miles and 280 miles. Therefore, if a small arc of a circle of equal altitudes, say 30 or 40 miles in length for altitudes less than 86°, is drawn upon a chart, it will be of such large radius that it will not vary appreciably from a straight line. For altitudes greater than 86° the line must be shorter, and for an altitude of 89° should not exceed 10 miles.

In Figure 4, the circle of equal altitudes was shown to be generated by the rotation of the line CA, of which line the terrestial end, A, traced the circle. The direction of CA from A is the true bearing of the body C because CA lies in the plane through the observer's zenith, the center of the earth and the body. Therefore, at every point of the circle of equal altitudes the latter will be perpendicular to the true bearing of the body from that point. Hence the straight line which represents an arc of the circle of equal altitudes of a body on a chart must be at right angles to the true bearing of that body.

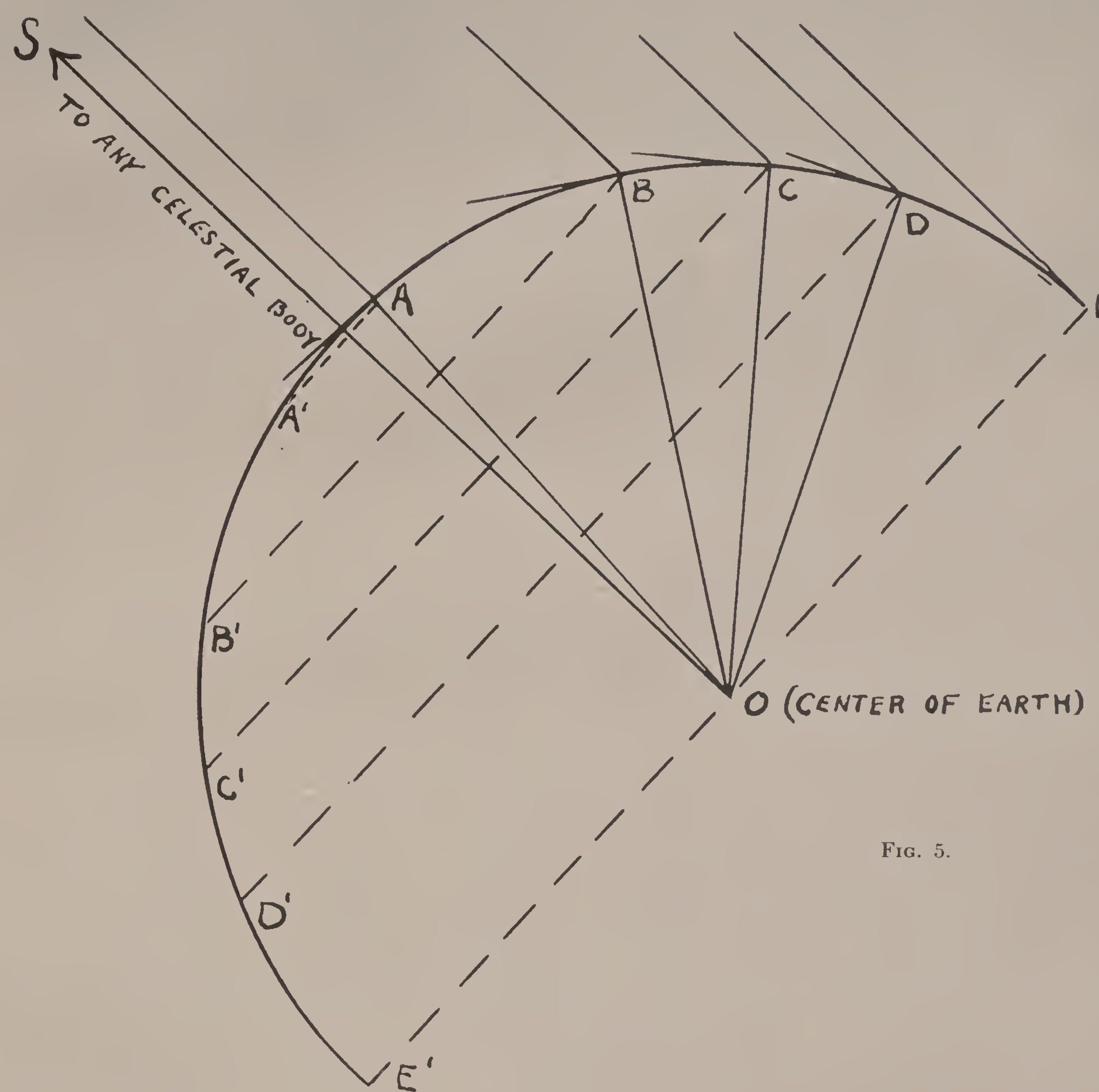


FIG. 5.

39. It has been shown that at any instant, for any body, there is a series of parallel circles of equal altitude upon the earth. If the altitude of such a body is observed, then the ship from which the observation is taken must be somewhere on that circle of equal altitude on which the altitude is the same as the observed altitude. As has been shown a straight line of moderate length may be drawn upon the chart to represent the circle of equal altitudes. Such a line, being the locus of the possible positions of the ship is a line of position. Its position upon the chart may be fixed as follows:

For the D.R. position and time of the observation, the azimuth, or true bearing of the body may be determined, A line may then be drawn upon the chart through the D.R. position in the direction of the body's bearing. Since a circle of equal altitudes is everywhere at right angles to the body's bearing, any straight line drawn at right angles to the bearing line of the body will represent a circle of equal altitudes. This fixes the direction of the required line of position. With the direction determined, it is necessary only to fix one point in order to draw the line. To do this the altitude is computed for the D.R. position and the time of observation. The difference in minutes of arc, between the computed altitude and the observed altitude will be the difference in miles between the circles of equal altitude which pass through the D.R. position and the actual position of the ship. (See Fig. 3.) Further, the circle of equal altitudes representing the locus of possible actual positions of the ship will be toward the observed body from the D.R. position, if the observed altitude is greater then the computed altitude. Similarly, the actual position will be away from the D.R. position if the observed altitude is less than the computed altitude. (See Fig. 5.) Therefore, the number of minutes in the altitude difference is measured as miles from the D.R. position on the bearing line, toward or away from the body. The line of position may then be drawn through the point thus determined, at right angles to the bearing line.

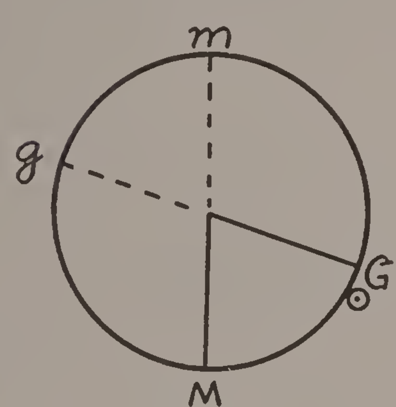
The following two examples will illustrate the method and form for work for finding the calculated altitude and azimuth. The problems are plotted in Figure 6 to illustrate the method of determining a fix by simultaneous lines of position. Example 1 is plotted in the upper part of the figure, and example 2 in the lower half.

Fix the Sun Line and Bearing.

Example 1. On 2 October, 1925, at about 7:35 A.M. in D.R. Position Lat. 37°–17′ N., Long. 75°–27′ W., the navigator of the U.S.S. Raleigh observed the sun for a line of position as follows: W 7–35–10; C-W 4–50–24; Chro. fast 3^m–03.9^s, Ht. of eye 18 ft., I.C. (−) 1–00, h_s ☉ 15–39–07. At the same instant the assistant navigator obtained the true bearing of Hog Island Light, 285°. Required the fix.

FIX BY SUN LINE AND BEARING.

2 October, 1925. Sun.



Lat.	37°–17′ N.
λ	75°–27′ W.
=	5^h–01^m–48^s

W		7–35–10
C-W		4–50–24
Chro. T.		12–25–34
Chro. fast	(−)	3–03.9
G.C.T.		12–22–30.1 (2 Oct.)
Eq.T.	(+)	10–32.8
G.A.T.		12–33–02.9
λ (W.)		5–01–48.0
L.A.T.		7–31–14.9
t (E.)		4–28–45.1
L		37–17 N.
d		3–29 S.
L ∼ d		40–46
z		74–16–15
H_c		15–43–45
H_o		15–46–45
a		3–00 miles toward

t		4–28.8
d		3.5 S.
L		37.3 N.
Eq. T.	(+)	10–32.5
Cor.	(+)	.3
Eq. T.	(+)	10–32.8
l. hav.		9.48593
l. cos.		9.90072
l. cos.		9.99920
l. hav.		9.38585
n. hav.		.24314
n hav.		.12131
n. hav.		.36445

t	d	L	Base
108–06	108–06	108–06	108–06
106–24	108–54	108–24	(−) 1–01
(−) 102	(+) 48	(+) 18	N 107–05 E.
(−) 90	(+) 24	(+) 5	Z_n 107–05

Dec.	(−)	3–28.6
Cor.	(+)	0.4
d		3–29.0 S.

h_s		15–39–07
I.C.	(−)	1–00
T. 46	(+)	8–35
Sub.	(+)	0–03
H_o		15–46–45

Fix by Simultaneous Observation of Two Stars.

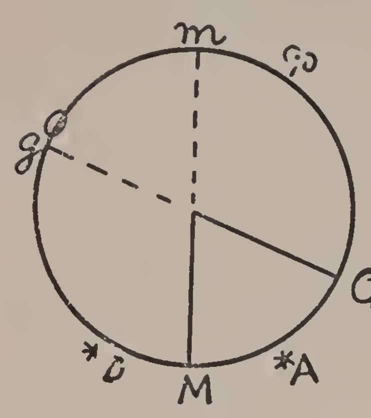
Example 2. On 2 July, 1925, during evening twilight, in D.R. position Lat. 36°–49′ N., Long. 75°–12′ W., the navigator of the U.S.S. Detroit and his assistant took simultaneous observations of stars β Leonis (Denebola) and α Scorpii (Antares) for lines of positions as follows: W = 7–24–21; C-W 5–03–39; Chro. slow 00m–39.8s, Ht. of eye 36 ft., I.C. (+) 1′–30. hs Denebola 51°–20′–10″; hs Antares 19°–27′–37″. Required the lines of position and the fix.

STAR FIX, SIMULTANEOUS OBSERVATIONS.

2 July, 1925. | Denebola. | Lat. 36–49 N.

Antares. | λ 75–12 W.

= 5h–00m–48s



		t	d	L		Base
t	2–24.7	114–46		114–46		114–46
d	15° N.	112–17	Denebola	115–56	(−)	14
		(−) 149		(+) 70	N	114–32 W.
L	36.8 N.	(−) 70		(+) 56	Zn	245–28
			Antares			
Sup. t.	9–45.1	33–13	33–13	33–13		33–13
d	26.3 S.	31–07	32–42	33–01	(−)	1–23
		(−) 126	(−) 31	(−) 12		31–50
L	36.8 N.	(−) 64	(−) 9	(−) 10	Zn	148–10

W	7–24–21						
C-W	5–03–39						
Chro. T.	0–28–00						
Chro. slow	(+) 0–39.8						
G.C.T.	0–28–39.8 (3 July)						
R.A.M.S.+12	18–41–59.9	hs	51–20–10			hs	19–27–37
T. III	0–04.7	I.C.	(+) 1–30			I.C.	(+) 1–30
G.S.T.	19–10–44.4	T. 46	(−) 6–40			T. 46	(−) 8–37
λ (W.)	5–00–48.0	Ho	51 15–00			Ho	19–20–30
L.S.T.	14–09–56.4			L.S.T.	14–09–56.4		
R.A.	11–45–14.4	Denebola		R.A.	16–24–50.5	Antares	
t (W.)	2–24–42	l. hav.	8.98404	t (E.)	2–14–54.1	l. hav.	8.92503
L	36–49–00 N.	l. cos.	9.90339	L	36–49–00 N.	l. cos.	9.90339
d	14–59–30 N.	l. cos.	9.98496	d	26–16–00 S.	l. cos.	9.95267
		l. hav.	8.87239			l. hav.	8.78109
		n. hav.	.07454			n. hav.	.06041
L ∼ d	21–49–30	n. hav.	.03584	L ∼ d	63–05–00	n. hav.	.27365
z	38–48–30	n. hav.	.11038	z	70–37–00	n. hav.	.33406
Hc	51–11–30			Hc	19–23–00		
Ho	51–15–00			Ho	19–20–30		
a	3–30 miles toward			a	2–30 miles away		

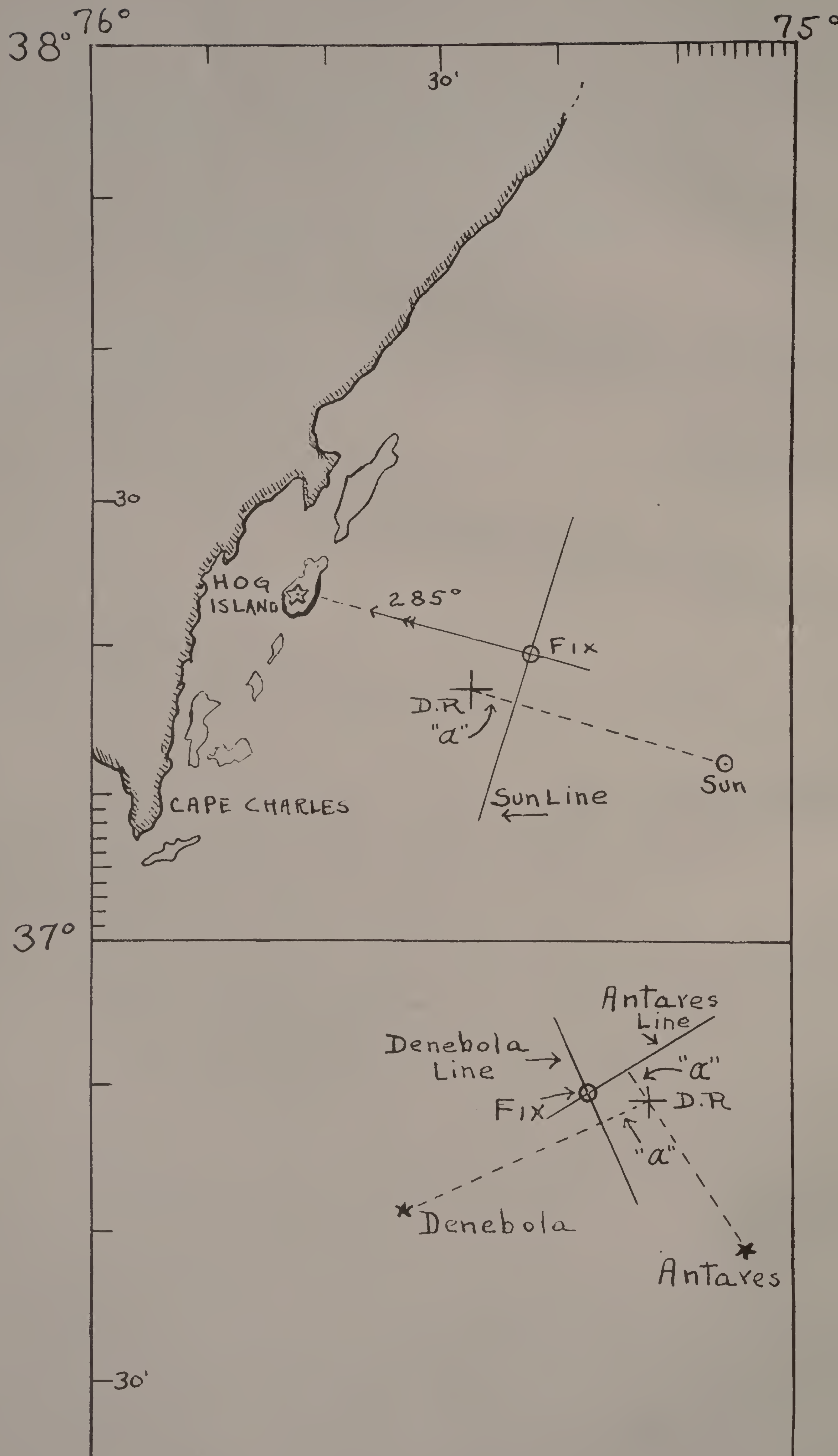

76°
75°
38°
30'
30
HOG ISLAND
285°
FIX
D.R
"a"
CAPE CHARLES
Sun Line
Sun
37°
Antares Line
Denebola Line
"a"
FIX
D.R
"a"
Denebola
Antares
30'

FIG. 6.

DEFINITIONS RELATING TO LINES OF POSITION.

PRINCIPLES FOR ADVANCING LINE OF POSITION.

40. In Figure 7, AB is the line of position obtained by observation of a body whose line of bearing is CD. D is the dead reckoning position. In this case the observed altitude is less than the calculated altitude and the line is plotted away from the body. Then C, the intersection of the line of position and the line of bearing, is the computed point. When only one line of position is obtained, the computed point is the most probable position of the ship on that line.

Current is the difference between the reckoned position for any instant and the position by fix for the same instant. The term is a very loose one, and embraces everything that causes the D.R. position to be in error. It includes effects of ocean currents, bad steering, wind, the state of the sea, the foulness of the ship's bottom, and, in general, everything that causes the navigator's account of the course and speed over the floor of the ocean to be in error. The set is the direction in which the current acts. The drift is the amount in miles per hour that the ship is carried in the direction of the set.

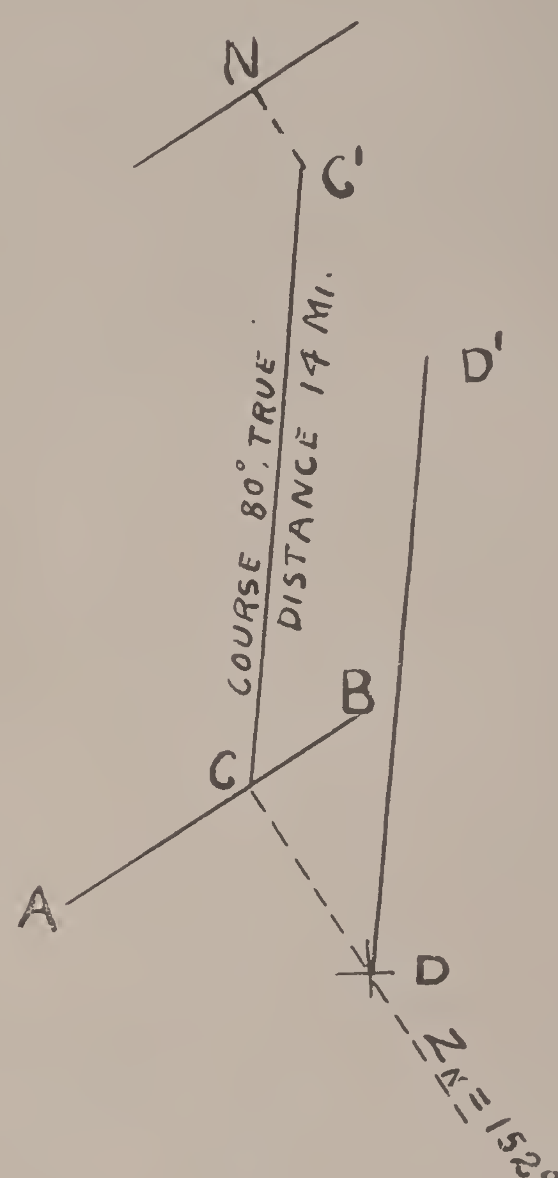


Fig. 7.

At sea it is customary to divide the navigational work into increments of one day's duration extending from clock noon to clock noon. The noon position each day is used as the origin of the day's work, or point of departure for that day. It is obvious that in case of leaving port or pilot waters that day may be shortened; but it continues until noon. Also, when changing the zone description, the day may not equal 24 hours.

Dead reckoning is carried along with the day's work and it is likewise limited by consecutive noons. The *dead reckoning position* (*D.R.*) at any time may be defined as the position obtained by applying the run to the last point of departure or origin of the day's work.

The *current reckoning position* (C.R.) originates with the latest fix. It is dead reckoning from the latest fix. Therefore, in the earlier stages of the day's work it may coincide with the D.R. position.

The navigator's position (N.P.) is the most favorable position or "best" position short of a fix. It is really the D.R. or C.R. position corrected for such current as may have been established. With only one line of position available the computed point is the navigator's position.

Current may be determined by means of a C.R. position and a fix, the line joining those points indicating the set by its direction, and the total drift by its length. The drift may be obtained by dividing the length in miles by the number of hours that have intervened between the preceding fix and the D.R. position.

Current when established must be allowed for when advancing a line of position. In solving problems it will be assumed that the current established between the two latest fixes is always to be used, and all previous current data will be neglected. In the practice of navigation at sea, due regard must be had for the reliability of the current established. The unavoidable small errors in observations may cause an abnormal current to be indicated between fixes obtained at short intervals. Abnormal atmospheric conditions may have the same effect. As the student is not in possession of the facts sufficient to enable him to judge the situation, the rule will be to always use the latest current established unless notified not to do so.

Total current cannot be obtained by means of a D.R. position and a single line of position, but some current information may be obtained therefrom. Thus, in Figure

7, the line CD represents the effect of the component of the current that has acted at right angles to the line of position. If it is desired to advance the line of position with no complete current determination available, it can be assumed that the effect of current in the direction at right angles to the line of position will continue at the same rate. Thus assume the D.R. position, D, to have been obtained by plotting the run from a point of departure five hours before, and let DC = 5 miles. Then the effect of the current acting in the line DC has been 1 mile per hour. Now assume the ship to proceed on the same course and speed for three hours and that it is desired to advance the line AB for this run. Advance the D.R. position for the run to D′, plotting DD′ for the direction and distance run. Advance the computed point for the run to C′. Draw C′N parallel to CD, and equal to three miles. Then N is the navigator's position, for it is the best position obtainable other than a fix. C′ is called the current reckoning position since it is used as the point to which the current component is applied, to obtain the navigator's position.

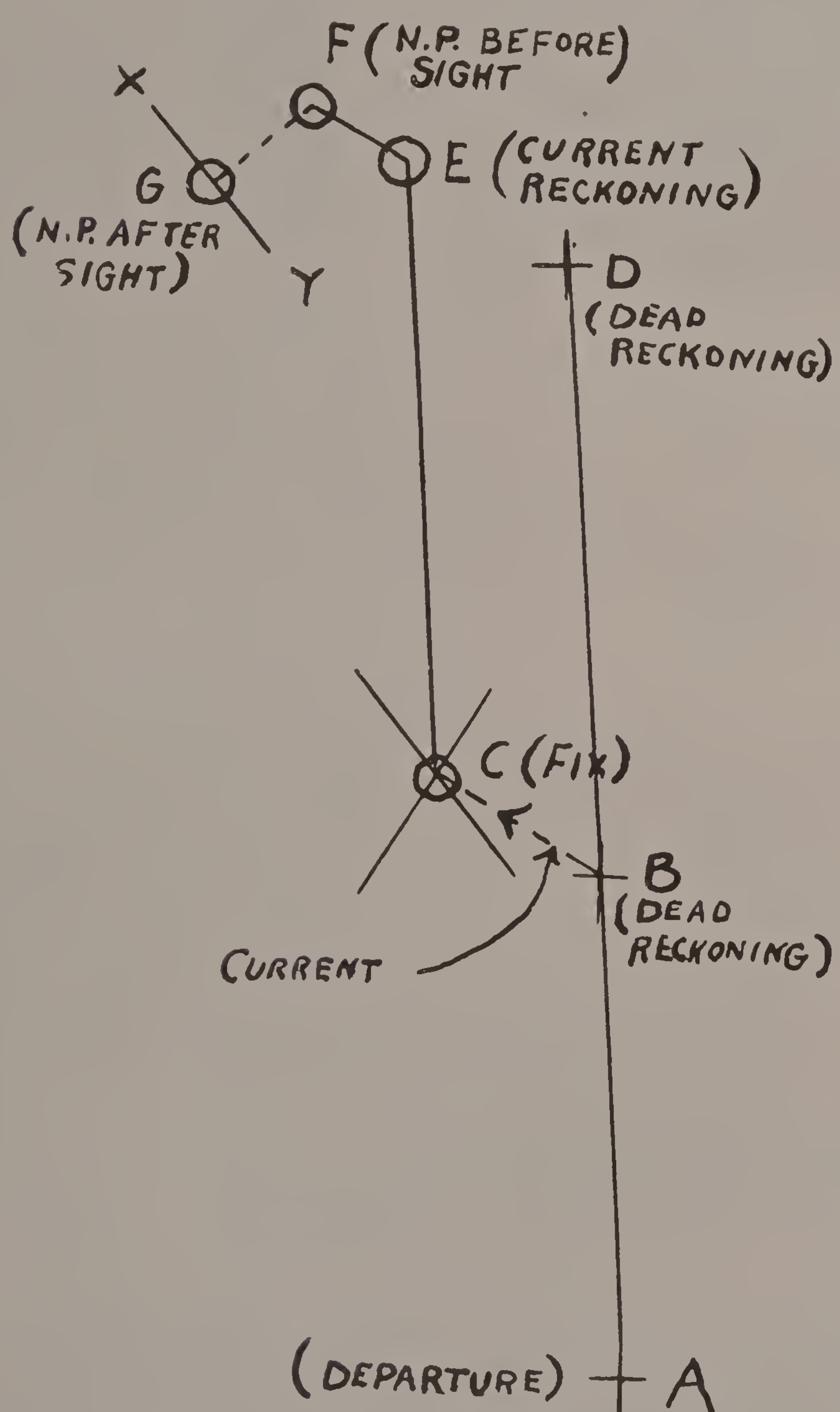


FIG. 8.

A current component should never be used when an established current is available.

41. Three points of the line of position have now been defined: the computed point, the navigator's position and the current reckoning position. Figure 8 will illustrate their use. A is a point of departure, AB is the run to time of simultaneous observations, C the fix from those observations. Then CB is the current. B is advanced to D by dead reckoning to time of next observation. C is similarly advanced to E, which is the current reckoning point. The current is applied to E by drawing EF parallel to CB, and making $\frac{EF}{CB}=\frac{CE}{AB}$. F is the navigator's position before sight is taken. A single sight is taken, giving the line XY. G, the computed point, is the navigator's position after sight. Continuing the run, the next current reckoning point is obtained by applying the D.R. run to G. The current reckoning point is always run up from the best previous position.

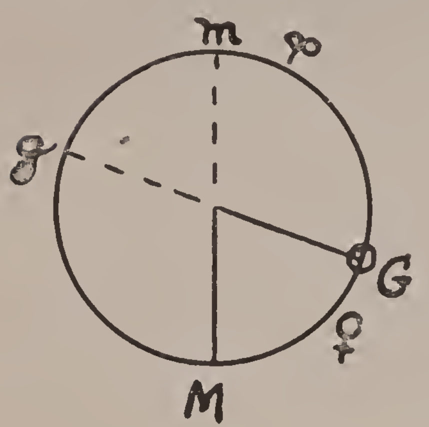
Examples 3 and 4 illustrate the method of obtaining a fix from observations taken at different times. Example 3 is plotted in the lower part of Figure 9, and example 4 in the upper part of the same figure.

Fix by Planet Line of Position Crossed With Meridian Altitude of Sun.

Example 3. A ship has steamed on course 345° true, speed 6 knots, since noon 1 January, 1925, without observations. At morning twilight 2 January observed the planet Venus for a line of position as follows: W 6–56–50; C-W 5–02–00; Chro. slow 1^m–07.3^s; h_s 17–13–11; Ht. of eye 14 ft., I.C. (−) 0–30″. The D.R. position at time of sight was Lat. 36°–28′ N.; Long. 74°–58′–30″ W. The ship then proceeds on same course and speed for 5 hrs. and 4 min. (until L.A.N.) when obtained latitude, by meridian altitude, to be 37°–07′ N. Required Noon D.R., C.R., N.P., and fix.

Planet Line of Position.

2 January, 1925. ♀ Venus



Lat.	36°–28′ N.
λ	74°–58′–30″ W.
=	4^h–59^m–54^s

			t	d	L	Base
t	3–06.8		135–46	135–46	135–46	135–46
d	21.5 S.		133–50	136–24	136–00	(−) 0–53
L	36.5 N.		(−) 116	(+) 38	(+) 14	N 134–53 E.
			(−) 79	(+) 19	(+) 7	Z_n 134–53

W		6–56–50
C-W		5–02–00
Chro. T.		11–58–50
Chro. slow	(+)	1–07.3
G.C.T.		11–59–57.3 (2 Jan.)
RAM☉+12		6–44–27.0
T. III		1–58.3
G.S.T.		18–46–22.6
L (W.)		4–59–54
L.S.T.		13–46–28.6
R.A.		16–53–17.0
t (E.)		3–06–48.4
L		36–28–00 N.
d		21–27–42 S.
L ∼ d		57–55–42
z		72–47–45
H_c		17–12–15
H_o		17–05 55
a		6–20 miles away

R.A.		16–50–38	Dec.		21–22.3 S.
Cor.	(+)	2–39	Cor.	(+)	5.4
R.A.		16–53–17	d		21–27.7 S.

l. hav.	9.19618
l. cos.	9.90537
l. cos.	9.96880
l. hav.	9.07035
n. hav.	.11759
n. hav.	.23452
n. hav.	.35211

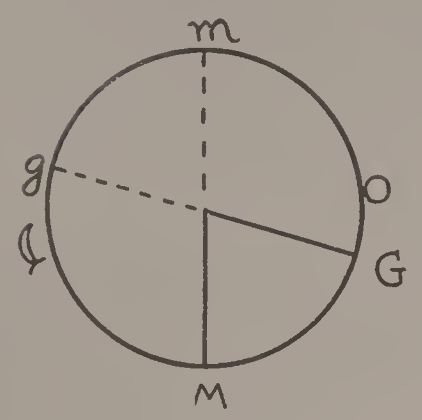
h_s		17–13–11
I.C.	(−)	0–30
T. 46	(−)	6–46
H_o		17–05–55

Fix by Moon Line of Position Advanced and Crossed With Sun Line of Position.

Example 4. On 3 October, 1925, at about 5:30 A.M., the U.S.S. Bobolink, with tow, is in D.R. Lat. 37°–50′ N., Long. 75°–05′ W. The navigator observes the lower limb of the moon for a line of position, as follows: W 5–50–00; C-W 5–02–00; Chro. slow 1^m–$07^s.3$; Ht. of eye 45 ft.; I.C. 0–00; h_s ☾ 14–48–00. The speed is 6 knots and the course is 190° true. The last fix was obtained at 6:00 P.M. 2 October. At 10:30 A.M. the sun is observed for a line of position and the following data obtained: $a = 4$ miles, $Z_n = 150°$. Required, the lines of position, the D.R., C.R., N.P., and fix at 10:30 A.M.

MOON LINE OF POSITION.

3 October. Moon.



Lat.		37°–50′ N.
λ	=	75°–05′ W.
	=	5^h–00^m–20^s

		t	d	L	Base
t	4–56.6	96–39	96–39	96–39	96–39
d	5.3 N.	95–05	95–49	96–57	(−) 1–03
L	37.8 N.	(−) 94	(−) 50	(+) 18	N 95–36 W.
		(−) 62	(−) 15	(+) 14	Z_n 264–24

W		5 50–00
C-W		5–02–00
Chro. T.		10–52–00
Chro. slow	(+)	1–07.3
G.C.T.		10–53–07.3 (3 Oct.)
R.A.M.S.+12		0–44–42.9
T. III		1–47.3
G.S.T.		11–39–37.5
λ (W.)		5–00–20.0
L.S.T.		6–39–17.5
R.A.		1–42–44.0
t (W.)		4–56–33.5
L		37–50–00 N.
d		5–16–18 N.
L ∼ d		32–33–42
Z.		74–15–35
H_c		15–44–25
H_o		15–50–08
a =		5–43 miles toward

R.A.		1–40–49
T. IV	(+)	1–55
R.A.		1–42–44
l. hav.		9.56033
l. cos.		9.89752
l. cos.		9.99816
l. hav.		9.45601
n. hav.		.28576
n. hav.		.07860
n. hav.		.36436

Dec.		5–05.6 N.
T. IV	(+)	10.7
d		5–16.3 N.
H.P.		583
h_s		14°–48′–00″
I.C.	(−)	0′–00″
T. 49	(+)	1°–02′–56″
Ht. of eye	(−)	0′–48″
H_o		15°–50′–08″

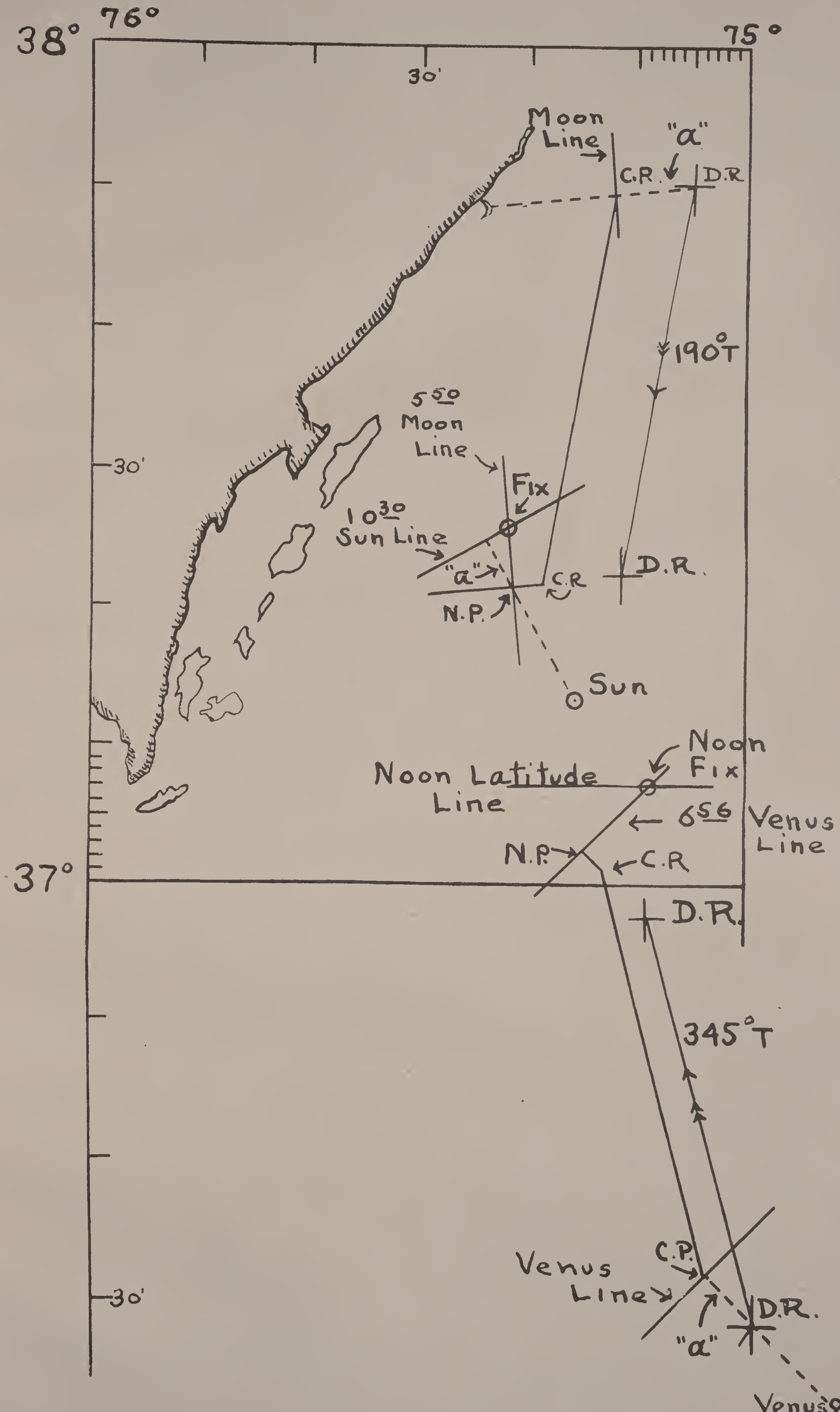

38°
76°
75°
30'
Moon
Line
"α"
C.R.
D.R
190°T
5 50
Moon
Line
Fix
10 30
Sun Line
"α"
C.R
D.R.
N.P.
30'
Sun
Noon
Fix
Noon Latitude
Line
6 56
Venus
Line
N.P.
C.R
37°
D.R.
345°T
C.P.
Venus
Line
D.R.
"α"
30'
Venus♀

FIG. 9.

SPECIAL USES OF LINES OF POSITION.

42. When on soundings, with only a single line of position available, a rough check on the position may be had by plotting the line on the chart for the instant at which an accurate sounding is taken. The position of the ship should then be at about that point on the line where the depth of water as given on the chart agrees with the result of the sounding.

By using a little foresight, it will frequently be possible to obtain a line of position by an observation of a body at the time its bearing is at right angles to the course. The resultant line of position will be parallel to the course. When the line is plotted it will be apparent at once which way the ship is being set from the course, and how much. Similarly a line may be obtained when the celestial body bears dead ahead or astern, giving a line which cuts the course at right angles. This gives an excellent check on the run.

It should be borne in mind that a line of position obtained by a bearing of a navigational point may be moved in the same manner as that described for lines obtained by observations of celestial bodies.

Thus in Figure 10, suppose a ship on the course XY. A and B are navigational points usually in sight at the same time. Visibility is low so that B cannot be seen when the bearing AX is taken. A is then lost, and after running the distance XX′, B is sighted, bearing in the direction BM. AX is moved up for the run to A′X′, and the fix obtained at F.

A radio bearing may be used as a line of position in any of the ways above described.

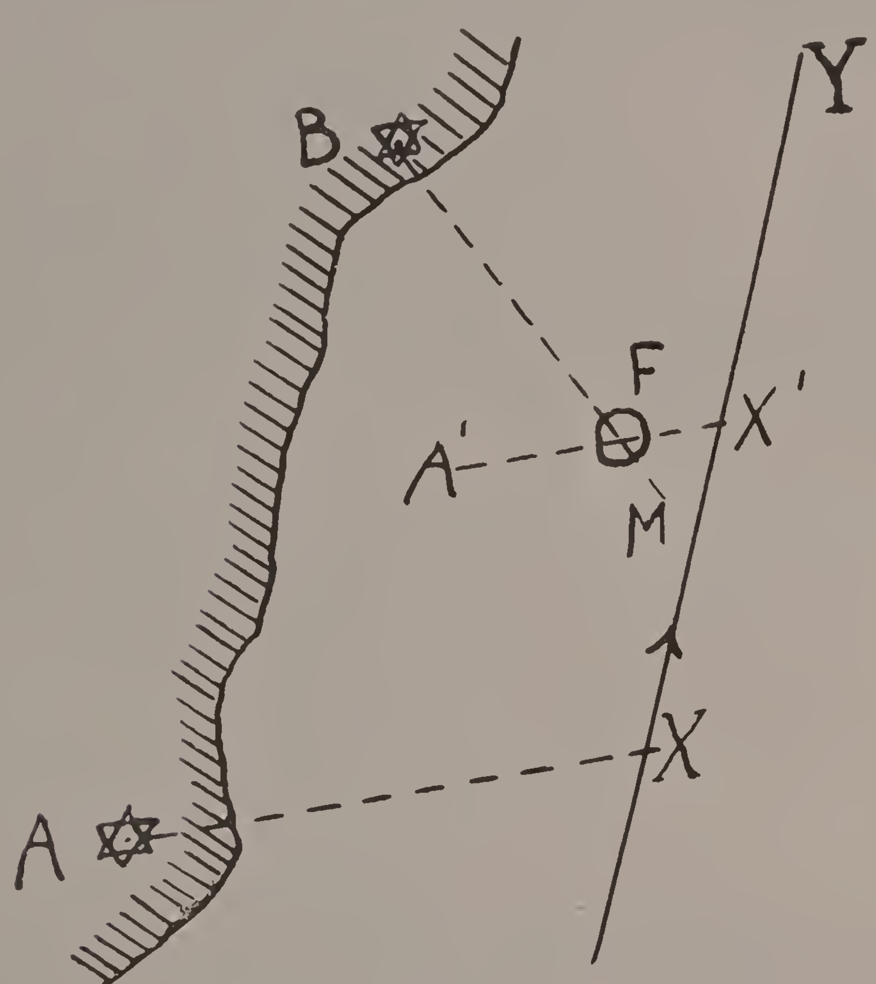


FIG. 10.

PROBLEMS.

1. The U.S.S. New York en route from Manila, P.I., to Valparaiso, Chile, is in D.R. position Lat. 32°–15′ S., Long. 88°–27′–00″ W., on 2 July, 1925. The navigator observes the sun for a line of position as follows: W = 11–10–22 A.M.; C-W = 5–56–23, Chro. fast 2^m–34^s, I.C. (−) 2′–30″, Ht. of eye 42 ft., h_s ☉̲ 33–11–30. Find the altitude difference and azimuth. ANSWERS: a = 2′–19″ towards, Z_n = 14°–59′.

2. On 2 May, 1925, in D.R. position Lat. 36°–00′ S., Long. 167°–00′ E., the navigator observed the sun as follows: W = 3–15–00 P.M. C-W = 1–56–04, Chro. fast 56^m–19^s, Ht. of eye 45 ft., I.C. (+) 2′–00″, h_s ☉̲ 19–13–30. Find the altitude difference and azimuth. ANSWERS: a = 2′–56″ away, Z_n = 306°–51′.

3. On 4 January, 1925, in D.R. position Lat. 19°–18′ N., Long. 72°–43′–30″ E., the navigator of a ship en route to Bombay observed the sun as follows: W = 3–24–33 P.M., C-W = 7–08–09, Chro. slow 3^m–50^s, h_s ☉̲ 25–02–15, Ht. of eye 25 ft., I.C. (+) 0′–30″. Find the altitude difference and azimuth ANSWERS: a = 5′–33″ towards, Z_n = 231°–52′.

4. On 4 October, 1925, at about 7:30 A.M. in D.R. position Lat. 37°–22′–15″ N., Long. 74°–16′–00″ W., observed the sun for a line of position as follows: W = 7–30–00, C-W = 4–28–03, Chro. slow 32^m–16^s.3 h_s ☉̲ 28–15–00, Ht. of eye 42 ft., I.C. (+) 1′–00″. Find the altitude difference and azimuth. ANSWERS: a = 1′–32″ away, Z_n = 121°–21′.

5. At sea 4 October, 1925, in D.R. position Lat. 48°–12′–15″ S., Long. 31°–02′–45″ W., during morning twilight, the navigator observed Sirius for a line of position as follows: W = 5–10–00, C-W = 2–03–30, Chro. slow 1^m–10^s, I.C. (+) 2′–15″, Ht. of eye 37 ft., h_s = 57–22–10. Find the altitude difference and azimuth. ANSWERS: a = 00′–58″ towards, Z_n = 18°–35′.

6. During evening twilight on 2 October, 1925, the navigator of the U.S.S. Chaumont in D.R. position Lat. 21°–18′ N., Long. 141°–24′ W., observed the star Antares for a line of position as follows: W = 6–02–10, C-W = 9–10–24, Chro. slow 15^m–18^s, h_s = 31–18–15. I.C. = (−) 1′–15″, Ht. of eye 35 ft. Find the altitude difference and azimuth. ANSWERS: a = 1′–54″ away, Z_n = 217°–38′.

7. At sea 2 July, 1925, in D.R. position Lat. 39°–38′ S., Long. 169°–17′ E., during evening twilight, observed the star Antares for a line of position as follows: W = 5–10–00 P.M., C-W = 00–33–09, Chro. fast 8^m–43^s, h_s = 28–35–00, I.C. (−) 1′–00″, Ht. of eye 42 ft. Find the altitude difference and azimuth. ANSWERS: a = 5′–48″ away, Z_n = 101°–48′.

8. A vessel en route from Constantinople, Turkey, to Odessa, Russia, is in D.R. position Lat. 46°–21′ N., Long. 30°–32′ E., on 2 May, 1925, P.M. At w.t. 7–21–14 observed the star Denebola for a line of position as follows: C-W = 8–01–16, Chro. fast 3^m–21^s, I.C. (−) 1′–30″, Ht. of eye 28 ft., h_s = 34–15–15. Find the altitude difference and azimuth. ANSWERS: a = 1′–09″ towards, Z_n = 75°–03′.

9. During evening twilight on 1 October, 1925, the navigator of a vessel in D.R. position Lat. 42°–53′ S., Long. 31°–40′–15″ E., observed the planet Venus for a line of position as follows: W = 7–00–00 C-W = 9–57–11, Chro. slow 5^m–18^s, h_s = 26–04–00, I.C. = (+) 1′–45″, Ht. of eye 54 ft. Find the altitude difference and azimuth. ANSWERS: a = 3′–59″ towards, Z_n = 268°–06′.

10. On 2 July, 1925, P.M. in D.R. position Lat. 15°–06′ N., Long. 134°–19′–15″ W., the navigator observed planet Saturn for a line of position as follows: W = 6–45–00, C-W = 8–51–16, Chro. slow 8^m–43^s, I.C. (−) 2′–30″, Ht. of eye 36 ft., h_s 60–05–00. Find the altitude difference and azimuth. ANSWERS: a = 2′–52″ away, Z_n = 152°–37′.

11. On 2 January, 1925, P.M. in D.R. Lat. 21°–05′ S., Long. 45°–40′ E., the navigator observes the lower limb of the moon for a line of position as follows: W = 7–05–06, C-W = 9–10–10, Chro. slow 01^m–00^s Ht. of eye 45 ft., I.C. 0′–00″, h_s ☾ 62–30–00. Find the altitude difference and azimuth. ANSWERS: a = 00–00–43″ away, Z_n = 154°–11′.

12. At sea in D.R. position Lat. 26°-17′ N., Long. 46°–02′ W., on 3 May, 1925, P.M., the navigator of a vessel observed the moon's lower limb for a line of position as follows: Wt. = 4–50–15, C-W = 3–08–16 Chro. fast 4^m–08^s, I.C. (+) 2′–00″, Ht. of eye 40 ft., h_s = 37–22–00. Find the altitude difference and azimuth. ANSWERS: a = 1′–56″ toward, Z_n = 99°–14′.

CHAPTER V.

A NAVIGATOR'S WORK AT SEA.

PREPARATIONS FOR LEAVING AND ENTERING PORT.

43. Before leaving port for a voyage, and when preparing to enter pilot waters, the navigator should examine all charts which are to be used to see that they are fully corrected to date. He should then study the charts, Sailing Directions, Light Lists and Tide Tables to make himself familiar with the waters to be traversed, the dangers to navigation therein, the characteristics of lights, markings of the channel, state of the tide at the hour set for sailing, probable set and drift of currents, areas in which icebergs may be encountered, and what radio compass stations are available for use. The course to be followed in pilot waters should be laid down on the harbor chart and bearings of prominent navigation marks should be determined for the points where the course is to be changed. These bearings should be laid down and noted on the chart. If the captain desires a pilot, or if the port regulations require that a pilot should be on board when leaving the harbor, the navigator should notify the local pilot's association or captain of the port.

The vicinity of the magnetic compass should be examined to see that no magnetic material has been stowed there. The navigator should see that the gyro compass is started at least four hours before sailing hour. If possible the error of the magnetic and gyro compass should be checked before getting underway. The chart board should be put in order and the necessary charts and gear laid out.

The chronometers are checked, the sextants, peloruses and azimuth circles adjusted. The sounding machine is overhauled and inventory made to insure that sufficient tubes are on hand. The lead lines are inspected for markings, to see that they are of proper length and placed in the chains ready for use. All steering gear from the several steering stations to the steering engine is carefully inspected and tested out, and arrangements for immediate shifting to hand steering should be included.

The Submarine Signal Receiving Apparatus should be placed in efficient working condition.

GENERAL DISCUSSION RELATING TO NAVIGATION WORK AT SEA.

44. The cosine-haversine formula by which the line of position is most often obtained is universally applicable for all combinations of meridian angle, latitude and declination, but is not generally used when the coordinates are within the limits of Tables 26 and 27, Bowditch.

There are several methods of obtaining the calculated altitude of celestial bodies without the use of logarithms; notably the methods of AQUINO, and that of H.O. publications 201 and 203. These short methods of finding the calculated altitude are not covered by the course of the Naval Academy, where, because of lack of time, only fundamentals can be taught. They should be studied when there is an opportunity and adopted if they suit the preference of the individual. Their use undoubtedly results in a saving of time and labor. Such methods are based upon a tabulation of the calculated altitude for given coordinates. Interpolation for other values of the coordinates is arranged for, but in order to reduce interpolations to a minimum it is usual to select the calculated altitude for an assumed position for which the coordinates agree with those used in the tabulations. This will give the same line of position as would be obtained by using the navigator's position and interpolating. *But, if an assumed position is used, the current component, which was explained in the preceding chapter, must be obtained by dropping a perpendicular from the navigator's position on the line of position. The perpendicular from the assumed position must never be used as a current component.*

It should be noted that lines of position which intersect at right angles give the most accurate fixes, other things being equal. While it is not often possible to select bodies whose bearings vary by 90°, this point should be borne in mind and when a choice is available those bodies whose bearings are most nearly at right angles should be selected. If an observation is taken when the body observed is on the prime vertical, *i. e.*, when it bears east or west, a line is obtained which runs north and south. Such a line is independent of any error in the reckoned latitude, and should be obtained if possible. Similarly, a line may be obtained which runs east and west and is independent of an error in reckoned longitude. This is the case of the meridian altitude.

Observed altitudes of less than 15° should be regarded as unreliable due to the uncertain effect of refraction. Altitudes of above 10° may be used if nothing better is available.

In taking observations with the sextant a series of at least five altitudes should be taken as rapidly as good observations can be had. A comparison of the differences in altitude with the differences in time between the five will usually show three observations in which the differences in altitude are proportional to the differences in time. Any one of these three may be used as correct.

The index error of the sextant should be determined every time the sextant is used.

A planet, being brighter than the stars, may be observed during the lightest part of twilight, when the horizon is clearly illuminated. Observed altitudes of planets may therefore be taken when the conditions are best for accurate measurement. After a little practice the altitude of Venus may be taken in broad daylight, when its R.A. differs by at least two hours from the sun's R.A. If its R.A. differs by less than two hours from that of the sun it will be in the brightly illuminated area surrounding the sun and will not be visible. As an aid in finding it the altitude and azimuth are calculated in advance for a given time. At that time the sextant is set for the calculated altitude and held in the direction of the bearing. The planet will be seen in the horizon mirror, a small disc having the dead white color of the moon when seen by daylight. A telescope should be used in the sextant and both telescope lenses and sextant mirrors must be perfectly clean.

In the method taught in the preceding pages the altitude of a planet is corrected by the use of the star column of Table 46, Bowditch. This correction is not complete for a planet; because the stars are at such a great distance from the earth that they have no measurable parallax, and that correction therefore is not included in Table 46. The correction for parallax for planets is small, not over 9″ and may be omitted; or, if it is desired to use it, it may be determined by means of the horizontal parallax tabulated in the Nautical Almanac and Table 17, Bowditch. If a further refinement is desired the altitude may be corrected for the semi-diameter which also will be found in the Nautical Almanac and may amount to as much as 0′.5.

The speed of the ship may be obtained by the patent log, or by means of the engine revolution counter. The latter is more accurate, especially if curves have been prepared showing the speed of the ship corresponding to the revolutions for various conditions of draft and the foulness of the ship's bottom. The reading of the patent log and the engine revolution counter should be recorded every hour, at times of changes in course, and at the time of taking observations.

Observations for the determination of the compass error should be taken when the body observed bears nearly east or west, as it is then changing its azimuth very slowly, and an error in the reckoned meridian angle has the least effect on the result.

The standard magnetic and gyro compass should be compared every half hour and the readings recorded. A change in the difference of their readings will then give an early indication of trouble in one or the other which must be investigated at once.

FINDING THE INTERVAL TO L.A.N., TODD'S METHOD.

45. The mean sun moves to the westward at the rate of 15° or 900′, of longitude in one hour. This is also the *average* rate of movement in longitude of the apparent sun. In considering the movement of the apparent sun for small periods of time its average rate may be used without material error. The meridian angle of the sun is determined for an instant in the forenoon, and this meridian angle is reduced to minutes (x) of arc. Then, at that instant the interval to L.A.N. will be $\frac{x}{900}$ hours. If the meridian angle is determined on a ship underway the interval to L.A.N. will be affected by the run of the ship Thus, if the ship is steaming to the eastward the rate of approach of the sun will be increased by the speed of the ship. Again, if the ship is steaming to the westward the rate of approach of the sun will be decreased by the speed of the ship. The current will affect the rate of approach of the sun in the same manner. Let $\Delta\lambda$ = the number of MINUTES OF LONGITUDE that a ship on a given course and speed covers in one hour. Let ΔC be the number of MINUTES OF LONGITUDE that the current sets the ship in one hour. Then the interval to L.A.N., in hours, will be:

$$\frac{\text{meridian angle for a given instant expressed in minutes of arc.}}{900 \pm \Delta\lambda \pm \Delta C}$$

In using the above method the ☉'s meridian angle should be determined at time of A.M. sight by subtracting the longitude of the best position from the G.A.T. of sight. Thus is a fix obtained, use the longitude of the fix, otherwise use the longitude of the navigator's position after sight (computed point). Similarly, use a fully established current if possible, otherwise a current component. $\Delta\lambda$ and ΔC may be obtained from the chart or from the traverse tables, remembering that what is required is the *minutes of longitude per hour.*

EXAMPLE: The fix at time of A.M. sight, taken when watch read 7–30–11, is Lat. 37°- 33′.5 N., Long. 72°–20′.9 W. = 4^h–49^m–23^s.6. W = 7–30–11, C-W = 4–55–51, Chro. 1–01 fast. The current is set 110°, drift 0.5 miles. Course is 85° true, speed 10 knots. Find the interval to L.A.N.

W	= 7–30–11		Long.	= 72–20–54.
C-W	= 4–55–51			= 4–49–23.6
CF	= 12–26–02	(Chronometer Face)		
CC	= (−) 1–01			
GCT	= 12–25–01	(2 May)		
ET	= (+) 3–02.5			
GAT	= 12–28–03.5			
λ	= 4–49–23.6 W.			
LAT	= 7–38–39.9			
t	= 4–21–20.1			
t	= 261.33		INT.	$= \dfrac{15 \times 261.33}{900+12.6+0.6}$

15			log	1.17609
261.33			log	2.41719
913.2	log 2.96057		colog	7.03943
	4.2925		log	.63271

Interval	= 4^h–17^m–33^s
W.T. of sight	= 7^h–30^m–11^s
W.T. LAN	= 11–47–44

46. If the course or speed is materially changed between forenoon sight and L.A.N. and in particular if any maneuvering is done during this period it will be necessary to allow for these changes in obtaining the time of L.A.N. If the Interval to L.A.N. based on a certain course and speed has already been found, and the time of L.A.N. and corresponding longitude obtained on this basis, a close approximation to the actual time of transit may be found by simply applying a correction for difference of longitude gained or lost due to the course or speed changes involved. Thus, if new conditions place the ship 10 minutes of longitude further to westward of original assumption for L.A.N., transit will be approximately 40 seconds later. However, a more accurate method is to solve again for interval to noon when the ship resumes a set course and speed. This does not involve the taking of a new sight, it is necessary only to find the L.A.T. corresponding to the new instant and to the longitude at that instant. Thus, in the above example, let it be assumed that the ship maneuvers on various courses at 15 knots from 8 to 11 a.m., when course 85° true, speed 10 knots is resumed. Assume that the plotted position of the ship at 11:00 watch time has been found to be Lat.

37°–35′, Long. 71°–35′.2.W. The L.A.T. corresponding to these conditions and the interval to noon are obtained by the standard method as follows:

W	= 11–00–00		= 71–35–12 W.
			= 4–46–20.8
C-W	= 4–55–51		
CF	= 15–55–51		
CC	= (−) 1–01 fast		
GCT	= 15–54–50 2 May		
ET	= (+) 3–03.6		
GAT	= 15–57–53.6		
λ	= 4–46–20.8 W.		
LAT	= 11–11–32.8		
t	= 0–48–27.2		
t	= 48.453 Minutes		

$$\text{Interval} = \frac{15 \times 48.453}{900+12.6+0.6}$$

15		log	1.17609
48.453		log	1.68532
913.2	log 2.96057	colog	7.03943
	.79586		9.90084

Int.	= 0^h–47^m–45.1^s
W.T.	= 11^h–00^m–00s
W.T. LAN	= 11^h–47^m–45.1^s

This method may of course be used even if no morning sight has been obtained and any resulting error will be practically proportional to the error in reckoned longitude, an error of 1 minute of arc causing an error of approximately 4 seconds of time.

THE DAY'S WORK.

47. The following is an outlne of the work required of the navigator every day at sea:

Dead Reckoning. The dead reckoning is carried forward as pure dead reckoning, regardless of fixes, from noon of one day to noon of the next day, or from time of departure to the succeeding noon. A comparison of the dead reckoning position at noon with the position by observation then gives the set and drift of the current for the preceding twenty-four hours.

The compass error is determined daily. It should be determined at morning and afternoon observations of the sun, and if possible, whenever the course is changed.

The sun should be observed in the forenoon and afternoon when on the prime vertical providing its altitude is then over 15°; otherwise as near the prime vertical as possible with an altitude exceeding 15°. The sun should also be observed at L.A.N.

At morning and evening twilight a fix should be obtained by at least two stars, or a star and a planet, selected so that the lines of position intersect at approximately a right angle.

Should any of the above observations be lost, due to clouds, or should circumstances render it advisable, additional sights of the sun, the moon, or of Venus, should be taken during daylight. When no fix has been obtained at morning twilight it is often possible to obtain an excellent fix during daylight by simultaneous observations of the sun and the moon or the sun and Venus. Lines of position obtained by observations as outlined above should be handled as described in the chapter on lines of position.

At 8:00 a.m., at noon, and at 8:00 p.m. the navigator is required to make a written report to the captain giving the results of his work. This report includes the position by D.R., and by observation, the set and drift of the current, the deviation of the compass, the course and distance made good, and the course and distance to destination.

The various steps of the navigator's work have already been taken up in detail. In the following example the steps are assembled. Results given are those obtained by plotting, and differ slightly from results by compution.

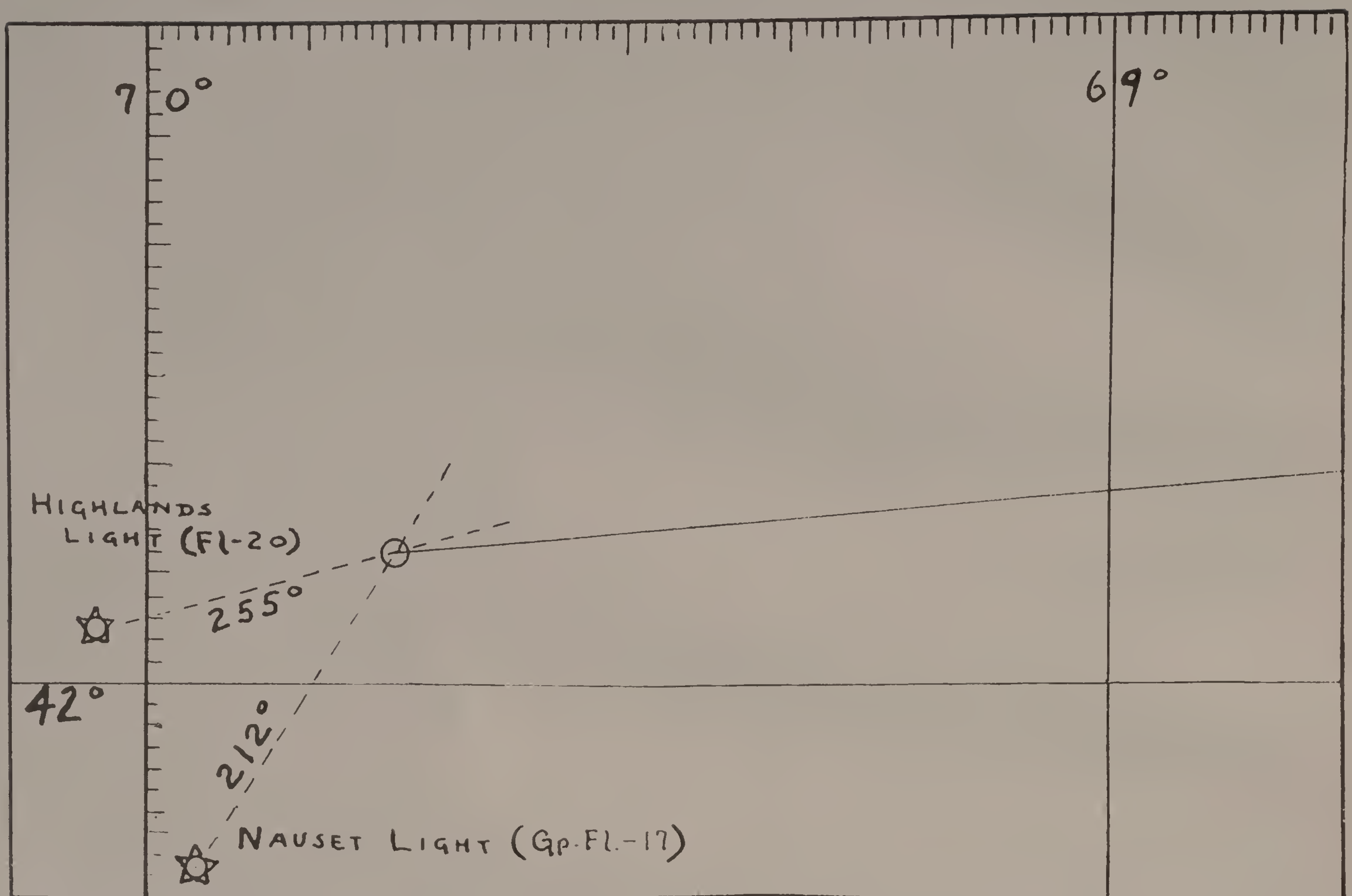


PLATE 1.

OBTAINING DEPARTURE.

Cross bearings.
Time: 2:00 A.M. July 2, 1925 (Zone+5)
"Highlands Light" bearing 255° true.
"Nauset Light" bearing 212° true.
2:00 A.M. Fix: { Lat. 42–06–00 N.
Long. 69–44–40 W.
Set course 85° true.
Speed 9 knots.
Weather overcast at dawn. No stars visible.

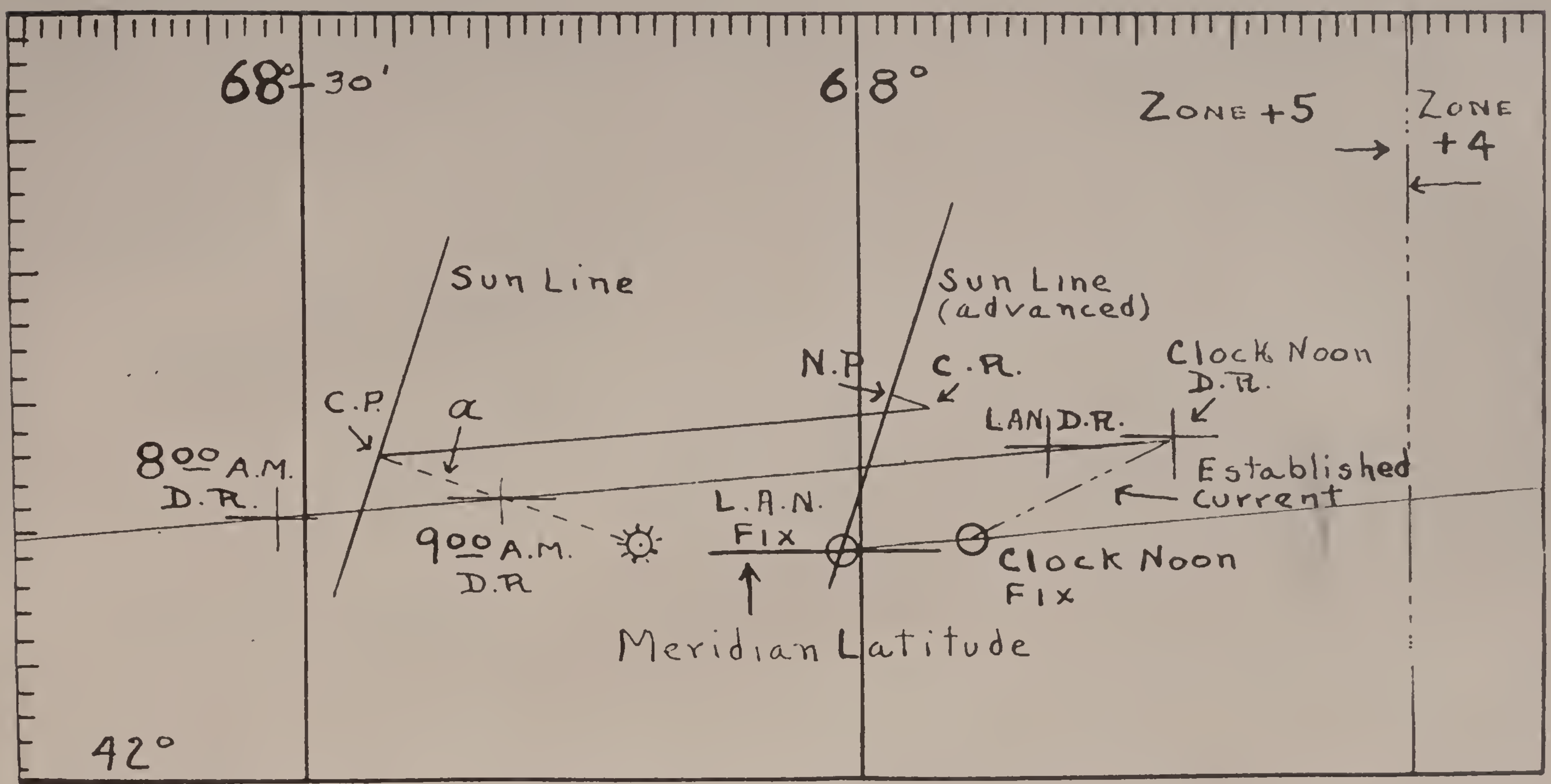


PLATE 2.

8:00 A.M. D.R.: Lat. 42°–10′–20″ N. Long. 68°–32′–00″ W.
At 9:00 A.M. observed sun for line of position, obtaining following data: a = 5 miles away, Zn = 108° true, Var. 16°–25′ W., Z p.s.c. = 127°, Dev. 2°–35′ W.

Positions at 9:00 A.M.:
D.R. Lat. 42°–11′–00″ N. Long. 68°–19′–45″ W.
C.P. Lat. 42°–12′–45″ N. Long. 68°–26′–00″ W.

Current component: $\frac{5 \text{ miles}}{7 \text{ hours}} = .71$ knots

Current component in λ = $\frac{6.5}{7} = .93'$ per hr. (W)

Speed component in λ = $12.3'$ per hr. (E)
Interval to L.A.N. = 2.45 hrs.
Run to L.A.N. = 9x2.45 = 22 miles.
Current: .71x2.45 = 1.7 miles.
L.A.N. positions:
D.R. Lat. 42–13–00 N. Long. 67–50–00 W.
C.R. Lat. 42–14–45 N. Long. 67–56–30 W.
N.P. Lat. 42–15–00 N. Long. 67–58–20 W.
Meridian Latitude = 42–09–00 N.
L.A.N. Fix: { Lat. 42–09–00 N.; Long. 68–01–00 W.
Run to clock noon = 5 miles (Current omitted).
Clock noon D.R. Lat. 42–13–10 N. Long. 67–43–30 W.
Clock noon Fix: { Lat. 42–09–10 N.; Long. 67–54–30 W.
Established current:
Set = 243°–30′
Drift = $\frac{9.2 \text{ Mi.}}{10 \text{ hrs.}} = .92$ mi/hr.
Made good: Course 87°–30′ true, speed 8.1 knots.

NOTE: The origin of the new D.R. is the clock noon fix. Continued course and speed until 2:00 P.M. at which time ship crossed from Zone Description + 5 to Zone Description + 4. Set all ships clocks ahead ONE hour.

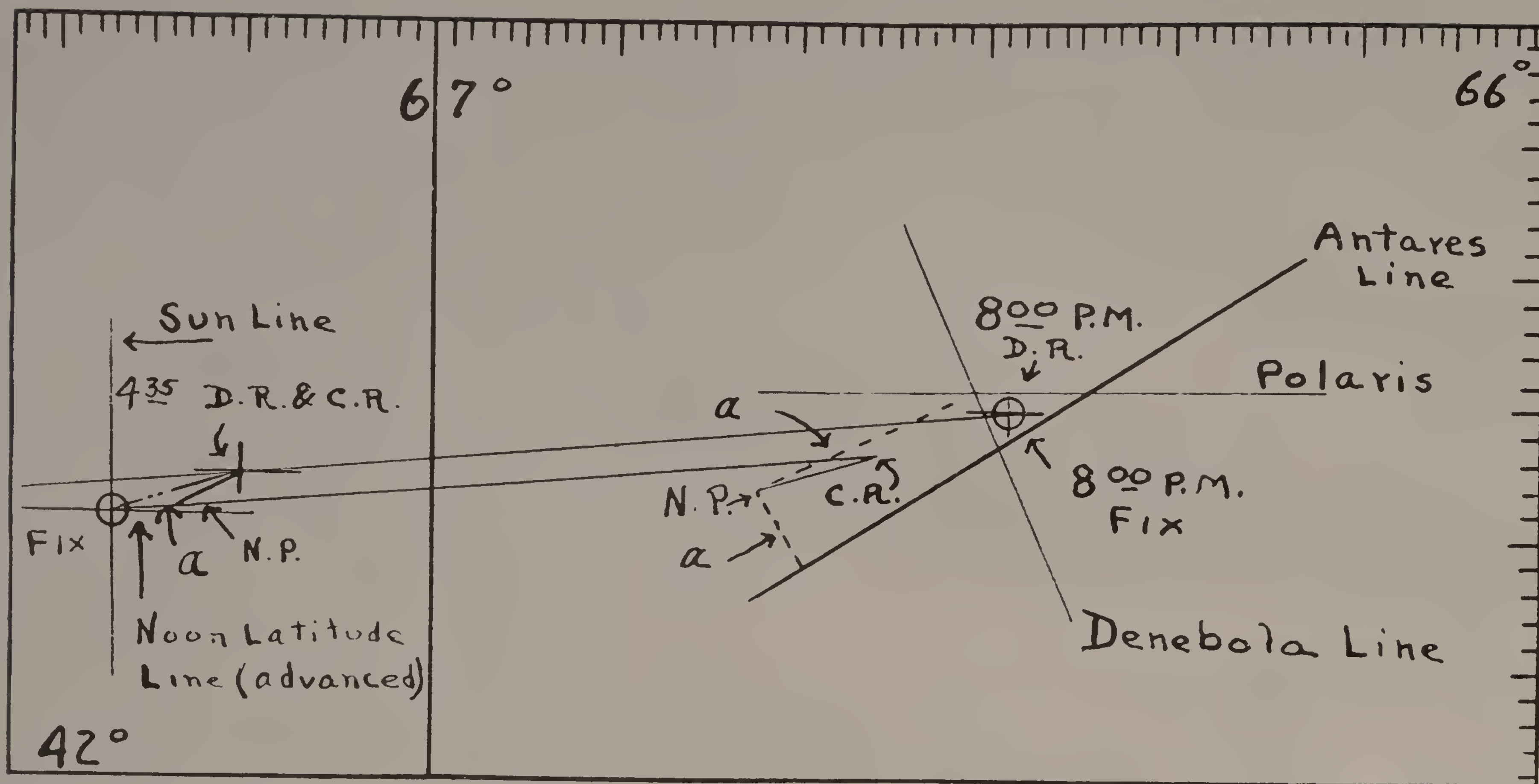


PLATE 3.

As before; on course 85° true, speed 9.
At 4:35 P.M. observed sun on prime vertical for line of position, obtaining following data:

Run to 4:35 P.M. = 3.6x9 = 32.4 miles.
Current = 3.6x.92 = 3.3 miles.
4:35 P.M. positions:
D.R. and C.R. Lat. 42–12–00 N. Long. 67–10–50 W.
N.P. Lat. 42–10–15 N. Long. 67–09–20 W.
Fix: Lat. 42–10–15 N. Long. 67–12–20 W.
Current: Set = 252°–50′

$$\text{Drift} = \frac{5.3}{3.6} = 1.47 \text{ mi/hr.}$$

Continued course and speed until 8:00 P.M. when observation of stars gave following data:

Run: 3.4 hrs. x 9 = 30.6 miles.
Current = 1.47 x 3.4 = 5 miles.
Polaris: Latitude 42–15–15 N.
Denebola: a = 9.6 miles away Zn = 246° true.
Antares: a = 3.6 miles towards Zn = 148° true.
Current = none.
8:00 P.M. Positions:
D.R. Lat. 42–14–30 N. Long. 66–28–40 W.
C.R. Lat. 42–13–00 N. Long. 66–36–00 W.
N.P. Lat. 42–12–30 N. Long. 66–42–25 W.
Fix Lat. 42–14–30 N. Long. 66–28–40 W.

NOTE: The center of the triangle formed by the stars' lines of positions coincides with the Dead Reckoning position. thus establishing the current as ZERO.

EXTRACTS FROM THE NAUTICAL ALMANAC, 1925.

For use in connection with the problems
contained in this book.

SUN, 1925.

Day of Month.	Sidereal Time of 0^h Civil Time at Greenwich (R. A. M. S.+12^h).			
	January.	May.	July.	October.
	h m s	h m s	h m s	h m s
1	6 40 30.4	14 33 36.9	18 34 6.8	0 36 49.8
2	6 44 27.0	14 37 33.4	18 38 3.4	0 40 46.3
3	6 48 23.5	14 41 30.0	18 41 59.9	0 44 42.9
4	6 52 20.1	14 45 26.5	18 45 56.5	0 48 39.4

JANUARY.

G.C.T.	Sun's Declination.	Equation of Time.
	Thursday 1.	
h	° ′	m s
0	−23 3.9	−3 20.9
2	23 3.5	3 23.2
4	23 3.1	3 25.6
6	23 2.7	3 28.0
8	23 2.3	3 30.4
10	23 1.9	3 32.8
12	23 1.5	3 35.1
14	23 1.1	3 37.5
16	23 0.7	3 39.9
18	23 0.3	3 42.2
20	22 59.8	3 44.6
22	22 59.4	3 47.0
H. D.	0.2	1.2
	Friday 2.	
0	−22 59.0	−3 49.3
2	22 58.6	3 51.7
4	22 58.1	3 54.0
6	22 57.7	3 56.4
8	22 57.3	3 58.7
10	22 56.8	4 1.1
12	22 56.4	4 3.4
14	22 56.0	4 5.8
16	22 55.5	4 8.1
18	22 55.1	4 10.4
20	22 54.6	4 12.8
22	22 54.2	4 15.1
H. D.	0.2	1.2
	Saturday 3.	
0	−22 53.7	−4 17.4
2	22 53.2	4 19.8
4	22 52.8	4 22.1
6	22 52.3	4 24.4
8	22 51.8	4 26.7
10	22 51.3	4 29.0
12	22 50.9	4 31.3
14	22 50.4	4 33.7
16	22 49.9	4 36.0
18	22 49.4	4 38.3
20	22 48.9	4 40.6
22	22 48.4	4 42.9
H. D.	0.2	1.2
	Sunday 4.	
0	−22 47.9	−4 45.2
2	22 47.4	4 47.4
4	22 46.9	4 49.7
6	22 46.4	4 52.0
8	22 45.9	4 54.3
10	22 45.4	4 56.6
12	22 44.9	4 58.9
14	22 44.3	5 1.1
16	22 43.8	5 3.4
18	22 43.3	5 5.7
20	22 42.8	5 8.0
22	−22 42.2	−5 10.2
H. D.	0.3	1.1

MAY.

G.C.T.	Sun's Declination.	Equation of Time.
	Friday 1.	
h	° ′	m s
0	+14 51.1	+2 51.2
2	14 52.6	2 51.8
4	14 54.2	2 52.5
6	14 55.7	2 53.1
8	14 57.2	2 53.8
10	14 58.7	2 54.4
12	15 0.2	2 55.1
14	15 1.8	2 55.7
16	15 3.3	2 56.3
18	15 4.8	2 57.0
20	15 6.3	2 57.6
22	15 7.8	2 58.2
H. D.	0.8	0.3
	Saturday 2.	
0	+15 9.3	+2 58.8
2	15 10.8	2 59.4
4	15 12.3	3 0.0
6	15 13.8	3 0.6
8	15 15.3	3 1.2
10	15 16.8	3 1.8
12	15 18.3	3 2.4
14	15 19.8	3 3.0
16	15 21.3	3 3.6
18	15 22.8	3 4.2
20	15 24.3	3 4.8
22	15 25.8	3 5.4
H. D.	0.7	0.3
	Sunday 3.	
0	+15 27.3	+3 5.9
2	15 28.8	3 6.5
4	15 30.2	3 7.1
6	15 31.7	3 7.6
8	15 33.2	3 8.2
10	15 34.7	3 8.7
12	15 36.2	3 9.3
14	15 37.6	3 9.8
16	15 39.1	3 10.4
18	15 40.6	3 10.9
20	15 42.0	3 11.4
22	15 43.5	3 12.0
H. D.	0.7	0.3
	Monday 4.	
0	+15 45.0	+3 12.5
2	15 46.4	3 13.0
4	15 47.9	3 13.5
6	15 49.4	3 14.1
8	15 50.8	3 14.6
10	15 52.3	3 15.1
12	15 53.7	3 15.6
14	15 55.2	3 16.1
16	15 56.6	3 16.6
18	15 58.1	3 17.1
20	15 59.5	3 17.6
22	+16 1.0	+3 18.1
H. D.	0.7	0.2

JULY.

G.C.T.	Sun's Declination.	Equation of Time.
	Wednesday 1.	
h	° ′	m s
0	+23 10.0	−3 27.6
2	23 9.7	3 28.6
4	23 9.4	3 29.6
6	23 9.1	3 30.6
8	23 8.7	3 31.5
10	23 8.4	3 32.5
12	23 8.1	3 33.5
14	23 7.8	3 34.4
16	23 7.4	3 35.4
18	23 7.1	3 36.4
20	23 6.8	3 37.3
22	23 6.4	3 38.3
H. D.	0.2	0.5
	Thursday 2.	
0	+23 6.1	−3 39.2
2	23 5.7	3 40.2
4	23 5.4	3 41.1
6	23 5.0	3 42.1
8	23 4.7	3 43.0
10	23 4.3	3 44.0
12	23 4.0	3 44.9
14	23 3.6	3 45.9
16	23 3.2	3 46.8
18	23 2.9	3 47.8
20	23 2.5	3 48.7
22	23 2.1	3 49.6
H. D.	0.2	0.5
	Friday 3.	
0	+23 1.8	−3 50.6
2	23 1.4	3 51.5
4	23 1.0	3 52.4
6	23 0.6	3 53.4
8	23 0.2	3 54.3
10	22 59.8	3 55.2
12	22 59.4	3 56.1
14	22 59.1	3 57.1
16	22 58.7	3 58.0
18	22 58.3	3 58.9
20	22 57.9	3 59.8
22	22 57.4	4 0.7
H. D.	0.2	0.5
	Saturday 4.	
0	+22 57.0	−4 1.6
2	22 56.6	4 2.5
4	22 56.2	4 3.4
6	22 55.8	4 4.3
8	22 55.4	4 5.2
10	22 55.0	4 6.1
12	22 54.5	4 7.0
14	22 54.1	4 7.9
16	22 53.7	4 8.8
18	22 53.2	4 9.7
20	22 52.8	4 10.6
22	+22 52.4	−4 11.5
H. D.	0.2	0.5

OCTOBER.

G.C.T.	Sun's Declination.	Equation of Time.
	Thursday 1.	
h	° ′	m s
0	−2 53.6	+10 3.6
2	2 55.6	10 5.2
4	2 57.5	10 6.8
6	2 59.5	10 8.4
8	3 1.4	10 10.1
10	3 3.4	10 11.7
12	3 5.3	10 13.3
14	3 7.2	10 14.9
16	3 9.2	10 16.5
18	3 11.1	10 18.1
20	3 13.1	10 19.7
22	3 15.0	10 21.3
H. D.	1.0	0.8
	Friday 2.	
0	−3 16.9	+10 23.0
2	3 18.9	10 24.6
4	3 20.8	10 26.2
6	3 22.8	10 27.8
8	3 24.7	10 29.4
10	3 26.6	10 31.0
12	3 28.6	10 32.5
14	3 30.5	10 34.1
16	3 32.4	10 35.7
18	3 34.4	10 37.3
20	3 36.3	10 38.9
22	3 38.3	10 40.5
H. D.	1.0	0.8
	Saturday 3.	
0	−3 40.2	+10 42.1
2	3 42.1	10 43.6
4	3 44.1	10 45.2
6	3 46.0	10 46.8
8	3 47.9	10 48.3
10	3 49.9	10 49.9
12	3 51.8	10 51.5
14	3 53.7	10 53.0
16	3 55.7	10 54.6
18	3 57.6	10 56.2
20	3 59.5	10 57.7
22	4 1.5	10 59.3
H. D.	1.0	0.8
	Sunday 4.	
0	−4 3.4	+11 0.8
2	4 5.3	11 2.4
4	4 7.3	11 3.9
6	4 9.2	11 5.5
8	4 11.1	11 7.0
10	4 13.1	11 8.6
12	4 15.0	11 10.1
14	4 16.9	11 11.6
16	4 18.9	11 13.2
18	4 20.8	11 14.7
20	4 22.7	11 16.2
22	−4 24.7	+11 17.8
H. D.	1.0	0.8

NOTE.—The Equation of Time is to be applied to the G.C.T. in accordance with the sign as given.
0^h Greenwich Civil Time is twelve hours before Greenwich Mean Noon of the same date.

MOON, 1925.

G.C.T.	Right Ascension.	Diff.	Declination.	Diff.	S.D.	H.P.
	January 1.					
h	h m s		° ′		′	′
0	23 59 51	248	− 3 58.7	223	15.6	57.3
2	0 3 59	248	3 36.4	223	15.6	57.2
4	0 8 7	247	3 14.1	223	15.6	57.1
6	0 12 14	246	2 51.8	223	15.6	57.1
8	0 16 20	245	2 29.5	223	15.6	57.0
10	0 20 25	245	2 7.2	223	15.5	56.9
12	0 24 30	243	1 44.9	223	15.5	56.8
14	0 28 33	243	1 22.6	222	15.5	56.8
16	0 32 36	243	1 0.4	222	15.5	56.7
18	0 36 39	241	0 38.2	222	15.5	56.6
20	0 40 40	241	− 0 16.0	221	15.4	56.5
22	0 44 41	241	+ 0 6.1	220	15.4	56.5
	January 2.					
0	0 48 42	240	+ 0 28.1	220	15.4	56.4
2	0 52 42	239	0 50.1	219	15.4	56.3
4	0 56 41	239	1 12.0	219	15.4	56.3
6	1 0 40	239	1 33.9	217	15.3	56.2
8	1 4 39	238	1 55.6	217	15.3	56.1
10	1 8 37	237	2 17.3	216	15.3	56.1
12	1 12 34	238	2 38.9	215	15.3	56.0
14	1 16 32	237	3 0.4	214	15.3	56.0
16	1 20 29	236	3 21.8	213	15.3	55.9
18	1 24 25	236	3 43.1	212	15.2	55.8
20	1 28 21	236	4 4.3	210	15.2	55.8
22	1 32 17	236	4 25.3	210	15.2	55.7
	January 3.					
0	1 36 13	236	+ 4 46.3	208	15.2	55.7
2	1 40 9	235	5 7.1	207	15.2	55.6
4	1 44 4	235	5 27.8	206	15.2	55.5
6	1 47 59	235	5 48.4	204	15.1	55.5
8	1 51 54	235	6 8.8	203	15.1	55.4
10	1 55 49	235	6 29.1	201	15.1	55.4
12	1 59 44	234	6 49.2	200	15.1	55.3
14	2 3 38	235	7 9.2	198	15.1	55.3
16	2 7 33	234	7 29.0	196	15.1	55.2
18	2 11 27	235	7 48.6	195	15.1	55.2
20	2 15 22	234	8 8.1	194	15.1	55.1
22	2 19 16	235	8 27.5	191	15.0	55.1
	January 4.					
0	2 23 11	235	+ 8 46.6	190	15.0	55.0
2	2 27 6	234	9 5.6	188	15.0	55.0
4	2 31 0	235	9 24.4	186	15.0	55.0
6	2 34 55	235	9 43.0	184	15.0	54.9
8	2 38 50	235	10 1.4	182	15.0	54.9
10	2 42 45	235	10 19.6	180	15.0	54.8
12	2 46 40	236	10 37.6	178	15.0	54.8
14	2 50 36	235	10 55.4	176	14.9	54.8
16	2 54 31	236	11 13.0	174	14.9	54.7
18	2 58 27	236	11 30.4	171	14.9	54.7
20	3 2 23	236	11 47.5	170	14.9	54.7
22	3 6 19	236	12 4.5	167	14.9	54.6
24	3 10 15		+12 21.2		14.9	54.6

G.C.T.	Right Ascension.	Diff.	Declination.	Diff.	S.D.	H.P.
	May 1.					
h	h m s		° ′		′	′
0	8 44 1	247	+18 5.0	106	14.9	54.5
2	8 48 8	247	17 54.4	110	14.9	54.5
4	8 52 15	246	17 43.4	112	14.9	54.5
6	8 56 21	247	17 32.2	116	14.9	54.6
8	9 0 28	246	17 20.6	120	14.9	54.6
10	9 4 34	246	17 8.6	122	14.9	54.6
12	9 8 40	245	16 56.4	126	14.9	54.7
14	9 12 45	246	16 43.8	129	14.9	54.7
16	9 16 51	245	16 30.9	133	14.9	54.7
18	9 20 56	245	16 17.6	135	14.9	54.8
20	9 25 1	244	16 4.1	138	15.0	54.8
22	9 29 5	245	15 50.3	142	15.0	54.8
	May 2.					
0	9 33 10	244	+15 36.1	144	15.0	54.9
2	9 37 14	244	15 21.7	147	15.0	54.9
4	9 41 18	244	15 7.0	151	15.0	54.9
6	9 45 22	244	14 51.9	153	15.0	55.0
8	9 49 26	243	14 36.6	156	15.0	55.0
10	9 53 29	244	14 21.0	160	15.0	55.1
12	9 57 33	243	14 5.0	162	15.0	55.1
14	10 1 36	243	13 48.8	164	15.1	55.2
16	10 5 39	243	13 32.4	168	15.1	55.2
18	10 9 42	243	13 15.6	170	15.1	55.3
20	10 13 45	243	12 58.6	173	15.1	55.3
22	10 17 48	242	12 41.3	175	15.1	55.4
	May 3.					
0	10 21 50	243	+12 23.8	178	15.1	55.4
2	10 25 53	242	12 6.0	181	15.1	55.5
4	10 29 55	243	11 47.9	183	15.2	55.5
6	10 33 58	242	11 29.6	186	15.2	55.6
8	10 38 0	243	11 11.0	188	15.2	55.6
10	10 42 3	242	10 52.2	190	15.2	55.7
12	10 46 5	243	10 33.2	193	15.2	55.7
14	10 50 8	242	10 13.9	195	15.2	55.8
16	10 54 10	243	9 54.4	198	15.2	55.9
18	10 58 13	243	9 34.6	199	15.3	55.9
20	11 2 16	242	9 14.7	202	15.3	56.0
22	11 6 18	243	8 54.5	204	15.3	56.0
	May 4.					
0	11 10 21	243	+ 8 34.1	206	15.3	56.1
2	11 14 24	243	8 13.5	208	15.3	56.2
4	11 18 27	244	7 52.7	210	15.3	56.2
6	11 22 31	243	7 31.7	212	15.4	56.3
8	11 26 34	244	7 10.5	213	15.4	56.3
10	11 30 38	244	6 49.2	216	15.4	56.4
12	11 34 42	244	6 27.6	217	15.4	5.65
14	11 38 46	245	6 5.9	219	15.4	5.65
16	11 42 51	244	5 44.0	221	15.5	56.6
18	11 46 55	245	5 21.9	222	15.5	56.7
20	11 51 0	246	4 59.7	223	15.5	56.7
22	11 55 6	246	4 37.4	226	15.5	56.8
24	11 59 12		+ 4 14.8		15.5	56.9

MOON, 1925.—*Continued.*

G.C.T.	Right Ascension.	Diff.	Declination.	Diff.	S.D.	H.P.
			July 1.			
h	h m s		° ′		′	′
0	13 51 31	254	− 5 54.1	230	15.7	57.7
2	13 55 45	255	6 17.1	228	15.8	57.8
4	14 0 0	255	6 39.9	228	15.8	57.8
6	14 4 15	257	7 2.7	228	15.8	57.9
8	14 8 32	258	7 25.5	226	15.8	58.0
10	14 12 50	260	7 48.1	225	15.9	58.1
12	14 17 10	260	8 10.6	224	15.9	58.2
14	14 21 30	262	8 33.0	224	15.9	58.2
16	14 25 52	263	8 55.4	221	15.9	58.3
18	14 30 15	264	9 17.5	221	15.9	58.4
20	14 34 39	266	9 39.6	219	16.0	58.5
22	14 39 5	267	10 1.5	217	16.0	58.6
			July 2.			
0	14 43 32	269	−10 23.2	216	16.0	58.6
2	14 48 1	269	10 44.8	213	16.0	58.7
4	14 52 30	272	11 6.1	212	16.0	58.8
6	14 57 2	272	11 27.3	210	16.1	58.9
8	15 1 34	275	11 48.3	208	16.1	59.0
10	15 6 9	275	12 9.1	206	16.1	59.0
12	15 10 44	277	12 29.7	203	16.1	59.1
14	15 15 21	279	12 50.0	201	16.2	59.2
16	15 20 0	280	13 10.1	198	16.2	59.3
18	15 24 40	282	13 29.9	195	16.2	59.3
20	15 29 22	283	13 49.4	193	16.2	59.4
22	15 34 5	285	14 8.7	189	16.2	59.5
			July 3.			
0	15 38 50	286	−14 27.6	187	16.3	59.6
2	15 43 36	288	14 46.3	183	16.3	59.6
4	15 48 24	290	15 4.6	180	16.3	59.7
6	15 53 14	291	15 22.6	176	16.3	59.8
8	15 58 5	293	15 40.2	173	16.3	59.9
10	16 2 58	294	15 57.5	169	16.4	59.9
12	16 7 52	295	16 14.4	166	16.4	60.0
14	16 12 47	298	16 31.0	161	16.4	60.1
16	16 17 45	298	16 47.1	157	16.4	60.1
18	16 22 43	301	17 2.8	154	16.4	60.2
20	16 27 44	302	17 18.2	148	16.4	60.3
22	16 32 46	303	17 33.0	145	16.5	60.3
24	16 37 49		−17 47.5		16.5	60.4
			July 4.			
0	16 37 49	305	−17 47.5	139	16.5	60.4
2	16 42 54	306	18 1.4	135	16.5	60.4
4	16 48 0	307	18 14.9	131	16.5	60.5
6	16 53 7	309	18 28.0	125	16.5	60.6
8	16 58 16	311	18 40.5	120	16.5	60.6
10	17 3 27	311	18 52.5	115	16.6	60.7
12	17 8 38	313	19 4.0	110	16.6	60.7
14	17 13 51	314	19 15.0	105	16.6	60.8
16	17 19 5	315	19 25.5	99	16.6	60.8
18	17 24 20	317	19 35.4	93	16.6	60.9
20	17 29 37	317	19 44.7	88	16.6	60.9
22	17 34 54	319	19 53.5	82	16.6	61.0

G.C.T.	Right Ascension.	Diff.	Declination.	Diff.	S.D.	H.P.
			October 1.			
h	h m s		° ′		′	′
0	23 32 45	273	− 7 4.1	247	16.3	59.6
2	23 37 18	272	6 39.4	248	16.3	59.6
4	23 41 50	271	6 14.6	250	16.3	59.6
6	23 46 21	271	5 49.6	251	16.2	59.5
8	23 50 52	270	5 24.5	251	16.2	59.5
10	23 55 22	270	4 59.4	253	16.2	59.5
12	23 59 52	269	4 34.1	253	16.2	59.4
14	0 4 21	268	4 8.8	254	16.2	59.4
16	0 8 49	268	3 43.4	255	16.2	59.4
18	0 13 17	267	3 17.9	255	16.2	59.3
20	0 17 44	266	2 52.4	255	16.2	59.3
22	0 22 10	266	2 26.9	255	16.2	59.2
			October 2.			
0	0 26 36	266	− 2 1.4	256	16.2	59.2
2	0 31 2	264	1 35.8	255	16.1	59.1
4	0 35 26	265	1 10.3	255	16.1	59.1
6	0 39 51	264	0 44.8	256	16.1	59.1
8	0 44 15	263	− 0 19.2	254	16.1	59.0
10	0 48 38	263	+ 0 6.2	255	16.1	59.0
12	0 53 1	262	0 31.7	253	16.1	58.9
14	0 57 23	262	0 57.0	253	16.1	58.9
16	1 1 45	262	1 22.3	253	16.0	58.8
18	1 6 7	262	1 47.6	251	16.0	58.7
20	1 10 29	261	2 12.7	251	16.0	58.7
22	1 14 50	260	2 37.8	249	16.0	58.6
			October 3.			
0	1 19 10	260	+ 3 2.7	249	16.0	58.6
2	1 23 30	260	3 27.6	247	16.0	58.5
4	1 27 50	260	3 52.3	246	16.0	58.5
6	1 32 10	260	4 16.9	244	15.9	58.4
8	1 36 30	259	4 41.3	243	15.9	58.3
10	1 40 49	259	5 5.6	242	15.9	58.3
12	1 45 8	259	5 29.8	239	15.9	58.2
14	1 49 27	258	5 53.7	238	15.9	58.2
16	1 53 45	259	6 17.5	236	15.9	58.1
18	1 58 4	258	6 41.1	234	15.8	58.0
20	2 2 22	258	7 4.5	233	15.8	58.0
22	2 6 40	258	7 27.8	230	15.8	57.9
24	2 10 58		+ 7 50.8		15.8	57.8
			Octbober 4.			
0	2 10 58	258	+ 7 50.8	228	15.8	57.8
2	2 15 16	257	8 13.6	225	15.8	57.8
4	2 19 33	258	8 36.1	224	15.8	57.7
6	2 23 51	257	8 58.5	221	15.7	57.7
8	2 28 8	258	9 20.6	219	15.7	57.6
10	2 32 26	257	9 42.5	216	15.7	57.5
12	2 36 43	258	10 4.1	213	15.7	57.5
14	2 41 1	257	10 25.4	211	15.7	57.4
16	2 45 18	257	10 46.5	209	15.6	57.3
18	2 49 35	257	11 7.4	205	15.6	57.3
20	2 53 52	258	11 27.9	203	15.6	57.2
22	2 58 10	257	11 48.2	199	15.6	57.1

MOON, 1925.—*Continued.*

TIME OF TRANSIT, MERIDIAN OF GREENWICH.

Date.	Greenwich Civil Time.		Date.	Greenwich Civil Time.		Date.	Greenwich Civil Time.		Date.	Greenwich Civil Time.	
	h m			h m			h m			h m	
Jan. 1	17 53	45	May 1	18 46	46	July 1	19 57	53	Oct. 1	23 45	51
2	18 38	45	2	19 32	46	2	20 50	57	3	0 36	49
3	19 23	44	3	20 18	46	3	21 47	60	4	1 25	49
4	20 7	45	4	21 4	48	4	22 47	64	5	2 14	50
5	20 52		5	21 52		5	23 51				

VENUS, 1925.

GREENWICH CIVIL TIME.

Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.	Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.
	h m s		° ′		h m		h m s		° ′		h m
Jan. 1	16 45 21	317	−21 10.8	115	10 5	May 1	2 38 53	290	+14 42.7	244	12 6
2	16 50 38	318	21 22.3	109	10 7	2	2 43 43	290	15 7.1	241	12 7
3	16 55 56	318	21 33.2	103	10 8	3	2 48 33	291	15 31.2	236	12 8
4	17 1 14	319	21 43.5	97	10 10	4	2 53 24	293	15 54.8	232	12 8
5	17 6 33	320	21 53.2	90	10 11	5	2 58 17	294	16 18.0	229	12 9
July 1	7 56 35	311	+22 10.1	133	13 23	Oct. 1	14 59 8	281	−18 19.5	232	14 23
2	8 1 46	310	21 56.8	140	13 24	2	15 3 49	282	18 42.7	226	14 24
3	8 6 56	309	21 42.8	146	13 26	3	15 8 31	283	19 5.3	223	14 24
4	8 12 5	307	21 28.2	152	13 27	4	15 13 14	284	19 27.6	217	14 25
5	8 17 12	307	21 13.0	158	13 28	5	15 17 58	284	19 49.3	213	14 26

JUPITER, 1925.

GREENWICH CIVIL TIME.

Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.	Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.
	h m s		° ′		h m		h m s		° ′		h m
Jan. 1	18 13 43	60	−23 15.5	2	11 32	May 1	19 36 42	7	−21 38.3	1	5 2
2	18 14 43	59	23 15.3	3	11 29	2	19 36 49	7	21 38.2	1	4 58
3	18 15 42	60	23 15.0	3	11 26	3	19 36 56	5	21 38.1	1	4 55
4	18 16 42	60	23 14.7	3	11 23	4	19 37 1	5	21 38.0	1	4 51
5	18 17 42	59	23 14.4	3	11 20	5	19 37 6	5	21 37.9	0	4 47
July 1	19 21 38	32	−22 19.5	12	0 47	Oct. 1	18 58 31	18	−23 7.1	4	18 19
2	19 21 6	32	22 20.7	11	0 43	2	18 58 49	18	23 6.7	4	18 15
3	19 20 34	32	22 21.8	12	0 38	3	18 59 7	20	23 6.3	4	18 12
4	19 20 2	33	22 23.0	12	0 34	4	18 59 27	20	23 5.9	4	18 8
5	19 19 29	33	22 24.2	12	0 30	5	18 59 47	21	23 5.5	5	18 4

SATURN, 1925.

GREENWICH CIVIL TIME.

Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.	Date.	Apparent Right Ascension. 0h		Apparent Declination. 0h		Transit, Meridian of Greenwich.
	h m s		° ′		h m		h m s		° ′		h m
Jan. 1	14 41 23	19	−13 16.3	13	8 0	May 1	14 37 58	18	−12 39.0	14	0 4
2	14 41 42	19	13 17.6	13	7 56	2	14 37 40	17	12 37.6	14	{ 0 0 23 56
3	14 42 1	19	13 18.9	12	7 52	3	14 37 23	18	12 36.2	13	23 52
4	14 42 20	18	13 20.1	12	7 49	4	14 37 5	18	12 34.9	14	23 47
5	14 42 38	18	13 21.3	12	7 45	5	14 36 47	17	12 33.5	14	23 43
July 1	14 24 43	4	−11 44.9	1	19 47	Oct. 1	14 42 34	25	−13 32.9	20	14 4
2	14 24 39	4	11 44.8	0	19 43	2	14 42 59	24	13 34.9	21	14 0
3	14 24 35	3	11 44.8	1	19 39	3	14 43 23	25	13 37.0	20	13 57
4	14 24 32	3	11 44.7	1	19 35	4	14 43 48	26	13 39.0	21	13 53
5	14 24 29	3	11 44.8	0	19 31	5	14 44 14	25	13 41.1	21	13 50

APPARENT PLACES OF STARS, 1925.

FOR THE UPPER TRANSIT AT GREENWICH.

No.	Constellation Name.	Right Ascension.	Jan. 1.	Feb. 1.	Mar. 1.	Apr. 1.	May 1.	June 1.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.	Dec. 32.
17	α Can. Maj.	6 41	51.3	51.3	50.9	50.4	49.8	49.6	49.6	50.1	50.8	51.6	52.5	53.3	53.7
18	ϵ Can. Maj.	6 55	41.7	41.8	41.4	40.7	40.1	39.7	39.7	40.1	40.8	41.6	42.6	43.4	43.9
19	α Can. Min.	7 35	23.2	23.4	23.2	22.7	22.3	22.0	22.0	22.3	22.9	23.7	24.6	25.5	26.1
20	β Gemin.	7 40	44.3	44.6	44.4	43.9	43.3	43.0	43.0	43.4	44.0	44.9	45.9	46.9	47.7
21	ϵ Argus	8 20	61.2	61.4	60.9	59.8	58.6	57.5	56.9	56.7	57.2	58.3	59.7	61.1	62.1
22	λ Argus	9 5	15.5	16.0	15.9	15.4	14.6	13.9	13.5	13.4	13.6	14.3	15.3	16.5	17.4
23	β Argus	9 12	26.8	27.4	27.1	25.8	24.1	22.3	20.9	20.2	20.4	21.6	23.4	25.4	27.1
24	α Hydræ.	9 23	54.6	55.1	55.2	54.9	54.5	54.1	53.8	53.8	54.1	54.6	55.4	56.4	57.3
25	α Leonis	10 4	22.9	23.5	23.8	23.6	23.3	22.8	22.6	22.5	22.7	23.1	23.9	24.8	25.8
26	α Urs. Maj.	10 59	6.5	7.9	8.6	8.5	7.8	6.8	5.9	5.2	5.1	5.6	6.7	8.3	10.2
27	β Leonis	11 45	13.7	14.5	15.1	15.2	15.1	14.8	14.4	14.1	14.0	14.2	14.7	15.5	16.5
28	α Crucis	12 22	25.1	26.7	27.7	28.0	27.8	27.1	26.0	25.0	24.2	24.0	24.7	26.0	27.8
29	γ Crucis	12 26	59.6	61.0	61.8	62.2	62.1	61.5	60.7	59.9	59.2	59.1	59.6	60.8	62.4
30	β Crucis	12 43	19.5	21.0	22.0	22.5	22.4	21.9	21.1	20.1	19.3	19.1	19.6	20.8	22.4
31	ϵ Urs. Maj.	12 50	42.7	44.2	45.2	45.8	45.7	45.1	44.3	43.5	42.8	42.6	43.0	43.9	45.4
32	ζ Urs. Maj.	13 20	53.0	54.5	55.6	56.3	56.3	55.8	55.1	54.3	53.5	53.2	53.3	54.1	55.4
33	α Virginis	13 21	13.5	14.4	15.1	15.6	15.8	15.7	15.4	15.0	14.7	14.6	14.8	15.4	16.3
34	θ Centauri	14 2	14.6	15.7	16.6	17.3	17.6	17.6	17.3	16.8	16.3	16.0	16.1	16.7	17.7
35	α Boötis	14 12	13.0	14.0	14.8	15.4	15.7	15.7	15.5	15.0	14.6	14.3	14.3	14.7	15.6
36	α Centauri	14 34	28.4	30.1	31.5	32.6	33.2	33.2	32.6	31.7	30.6	29.8	29.7	30.4	31.9
37	β Urs. Min.	14 50	50.6	53.1	55.5	57.5	58.3	57.8	56.2	54.0	51.6	49.8	48.8	49.1	50.7
38	α Cor. Bor.	15 31	28.9	29.9	30.8	31.6	32.1	32.3	32.2	31.8	31.3	30.7	30.5	30.7	31.3
39	δ Scorpii	15 55	51.9	52.8	53.7	54.6	55.2	55.6	55.7	55.4	54.9	54.4	54.2	54.4	55.1
40	α Scorpii	16 24	46.3	47.2	48.2	49.1	49.9	50.4	50.5	50.3	49.8	49.3	48.9	49.1	49.7
41	α Tri. Aust.	16 40	38.1	40.1	42.2	44.4	46.2	47.3	47.5	46.7	45.3	43.8	42.7	42.7	43.8
42	η Ophiuchi	17 6	2.4	3.2	4.0	5.0	5.7	6.3	6.6	6.4	6.0	5.5	5.1	5.1	5.6
43	λ Scorpii	17 28	28.3	29.2	30.2	31.3	32.3	33.0	33.4	33.3	32.8	32.2	31.7	31.6	32.1
44	α Ophiuchi	17 31	25.2	25.8	26.6	27.5	28.2	28.8	29.1	29.0	28.6	28.0	27.5	27.4	27.7
45	γ Draconis	17 54	49.4	50.1	51.0	52.3	53.4	54.1	54.3	54.0	53.1	52.1	51.1	50.6	50.7
46	ϵ Sagittarii	18 19	9.0	9.7	10.6	11.7	12.7	13.6	14.1	14.2	13.9	13.2	12.7	12.5	12.7
47	α Lyræ	18 34	21.8	22.3	23.0	24.0	25.0	25.8	26.2	26.1	25.6	24.9	24.1	23.7	23.7

APPARENT PLACES OF STARS, 1925.—*Continued.*

FOR THE UPPER TRANSIT AT GREENWICH.

No.	Declination.														Special Name.	Mag.
		Jan. 1.	Feb. 1.	Mar. 1.	Apr. 1.	May 1.	June 1.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.	Dec. 32.		
17	−16	36.9	37.0	37.1	37.1	37.0	37.0	36.9	36.8	36.7	36.7	36.7	36.8	36.9	Sirius	−1.6
18	−28	52.3	52.4	52.4	52.5	52.5	52.4	52.3	52.1	52.0	52.0	52.0	52.1	52.3	Adhara	1.6
19	+ 5	25.0	24.9	24.9	24.9	24.9	25.0	25.0	25.0	25.1	25.1	25.0	25.0	24.9	Procyon	0.5
20	+28	12.4	12.4	12.4	12.5	12.5	12.5	12.5	12.4	12.4	12.4	12.3	12.3	12.3	Pollux	1.2
21	−59	16.0	16.2	16.3	16.5	16.5	16.4	16.3	16.1	16.0	15.9	15.9	16.0	16.1		1.7
22	−43	7.7	7.8	8.0	8.1	8.1	8.1	8.0	7.9	7.7	7.7	7.6	7.7	7.9		2.2
23	−69	24.3	24.5	24.7	24.8	24.9	24.9	24.8	24.7	24.5	24.4	24.3	24.4	24.5	Miaplacidus	1.8
24	− 8	20.0	20.1	20.1	20.2	20.2	20.1	20.1	20.0	20.0	20.0	20.0	20.1	20.2	Alphard	2.2
25	+12	20.0	19.9	19.9	19.9	20.0	20.0	20.0	20.0	20.0	20.0	19.9	19.8	19.7	Regulus	1.3
26	+62	9.1	9.2	9.3	9.4	9.5	9.6	9.6	9.5	9.3	9.2	9.0	8.9	8.8	Dubhe	2.0
27	+14	59.4	59.4	59.4	59.4	59.4	59.5	59.5	59.5	59.5	59.4	59.4	59.2	59.1	Denebola	2.2
28	−62	40.6	40.8	40.9	41.4	41.3	41.3	41.4	41.3	41.2	41.1	41.0	40.9	41.0	Acrux	1.1
29	−56	41.2	41.4	41.5	41.7	41.8	41.9	41.9	41.9	41.8	41.7	41.5	41.5	41.6		1.6
30	−59	16.4	16.5	16.6	16.8	16.9	17.1	17.1	17.0	17.0	16.8	16.7	16.7	16.7		1.5
31	+56	21.8	21.8	21.8	21.9	22.1	22.2	22.2	22.2	22.1	22.0	21.8	21.6	21.5	Alioth	1.7
32	+55	18.8	18.8	18.8	18.9	19.1	19.2	19.2	19.2	19.2	19.0	18.8	18.7	18.5	Mizar	2.2
33	−10	46.1	46.2	46.2	46.3	46.3	46.3	46.3	46.3	46.2	46.2	46.2	46.3	46.4	Spica	1.2
34	−35	59.8	59.9	60.0	60.1	60.2	60.3	60.3	60.3	60.2	60.2	60.1	60.1	60.1		2.3
35	+19	34.3	34.2	34.2	34.2	34.3	34.4	34.4	34.5	34.4	34.4	34.3	34.2	34.0	Arcturus	0.2
36	−60	31.2	31.2	31.3	31.4	31.6	31.7	31.8	31.8	31.8	31.7	31.6	31.5	31.4	Rigil Kentaurus	0.1
37	+74	27.6	27.5	27.5	27.6	27.7	27.9	28.2	28.2	28.0	27.9	27.7	27.5	27.3	Kochab	2.2
38	+26	58.0	57.9	57.8	57.8	57.9	58.0	58.1	58.2	58.2	58.2	58.0	57.9	57.8	Alphecca	2.3
39	−22	24.4	24.4	24.5	24.5	24.6	24.6	24.6	24.6	24.6	24.6	24.5	24.5	24.6	Dschubba	2.5
40	−26	15.8	15.8	15.9	15.9	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	Antares	1.2
41	−68	53.3	53.2	53.2	53.3	53.4	53.5	53.6	53.7	53.8	53.7	53.6	53.5	53.4		1.9
42	−15	37.9	37.9	37.9	38.0	38.0	37.9	37.9	37.9	37.9	37.9	37.9	37.9	38.0	Sabik	2.6
43	−37	2.9	2.8	2.8	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.0	3.0	2.9	Shaula	1.7
44	+12	36.9	36.8	36.7	36.7	36.7	36.8	36.9	37.0	37.0	37.0	37.0	36.9	36.8	Rasalhague	2.1
45	+51	29.9	29.7	29.6	29.6	29.7	29.8	30.0	30.1	30.2	30.2	30.1	30.0	29.8	Etamin	2.4
46	−34	25.2	25.2	25.1	25.1	25.1	25.1	25.2	25.2	25.3	25.3	25.3	25.2	25.2	Kaus Australis	2.0
47	+38	42.9	42.7	42.6	42.6	42.6	42.8	42.9	43.0	43.1	43.2	43.1	43.0	42.9	Vega	0.1

MERIDIAN TRANSIT OF STARS, 1925.

GREENWICH CIVIL TIME OF TRANSIT AT GREENWICH.

Constellation Name.	Mag.	Jan. 1.	Feb. 1.	Mar. 1.	Apr. 1.	May 1.	June 1.	July 1.	Aug. 1.	Sept. 1.	Oct. 1.	Nov. 1.	Dec. 1.
α Can. Maj.	−1.6	0 1 / 23 57	21 56	20 5	18 4	16 6	14 4	12 6	10 4	8 2	6 4	4 2	2 4
ε Can. Maj.	1.6	0 15	22 9	20 19	18 17	16 19	14 18	12 20	10 18	8 16	6 18	4 16	2 18
α Can. Min.	0.5	0 55	22 49	20 59	18 57	16 59	14 57	12 59	10 57	8 55	6 57	4 56	2 58
β Gemin.	1.2	1 0	22 54	21 4	19 2	17 4	15 2	13 4	11 3	9 1	7 3	5 1	3 3
ε Argus	1.7	1 40	23 34	21 44	19 42	17 44	15 43	13 45	11 43	9 41	7 43	5 41	3 43
λ Argus	2.2	2 24	0 22	22 28	20 27	18 28	16 27	14 29	12 27	10 25	8 27	6 25	4 27
β Argus	1.8	2 31	0 30	22 36	20 34	18 36	16 34	14 36	12 34	10 32	8 34	6 32	4 34
α Hydræ	2.2	2 43	0 41	22 47	20 45	18 47	16 45	14 47	12 46	10 44	8 46	6 44	4 46
α Leonis	1.3	3 23	1 21	23 27	21 26	19 28	17 26	15 28	13 26	11 24	9 26	7 24	5 26
α Urs. Maj.	2.0	4 18	2 16	0 26	22 20	20 22	18 20	16 22	14 21	12 19	10 21	8 19	6 21
β Leonis	2.2	5 4	3 2	1 12	23 6	21 8	19 6	17 8	15 6	13 5	11 7	9 5	7 7
α Crucis	1.1	5 41	3 39	1 49	23 43	21 45	19 43	17 45	15 44	13 42	11 44	9 42	7 44
γ Crucis	1.6	5 46	3 44	1 54	23 48	21 50	19 48	17 50	15 48	13 46	11 48	9 46	7 48
β Crucis	1.5	6 2	4 0	2 10	0 8	22 6	20 4	18 6	16 4	14 2	12 5	10 3	8 5
ε Urs. Maj.	1.7	6 9	4 7	2 17	0 15	22 13	20 12	18 14	16 12	14 10	12 12	10 10	8 12
ζ Urs. Maj.	2.2	6 39	4 37	2 47	0 45	22 44	20 42	18 44	16 42	14 40	12 42	10 40	8 42
α Virginis	1.2	6 40	4 38	2 48	0 46	22 44	20 42	18 44	16 42	14 40	12 42	10 40	8 42
θ Centauri	2.3	7 21	5 19	3 29	1 27	23 25	21 23	19 25	17 23	15 21	13 23	11 21	9 23
α Boötis	0.2	7 31	5 29	3 39	1 37	23 35	21 33	19 35	17 33	15 31	13 33	11 31	9 33
α Centauri	0.1	7 53	5 51	4 1	1 59	0 1 / 23 57	21 55	19 57	17 55	15 53	13 55	11 54	9 56
β Urs. Min.	2.2	8 9	6 7	4 17	2 15	0 17	22 12	20 14	18 12	16 10	14 12	12 10	10 12
α Cor. Bor.	2.3	8 50	6 48	4 58	2 56	0 58	22 52	20 54	18 52	16 50	14 52	12 50	10 52
δ Scorpii	2.5	9 14	7 12	5 22	3 20	1 22	23 16	21 18	19 16	17 15	15 17	13 15	11 17
α Scorpii	1.2	9 43	7 41	5 51	3 49	1 51	23 45	21 47	19 45	17 43	15 45	13 44	11 46
α Tri. Aust.	1.9	9 59	7 57	6 7	4 5	2 7	0 5	22 3	20 1	17 59	16 1	14 0	12 2
η Ophiuchi	2.6	10 24	8 22	6 32	4 30	2 32	0 30	22 28	20 26	18 25	16 27	14 25	12 27
λ Scorpii	1.7	10 46	8 44	6 54	4 52	2 54	0 53	22 51	20 49	18 47	16 49	14 47	12 49
α Ophiuchi	2.1	10 49	8 47	6 57	4 55	2 57	0 56	22 54	20 52	18 50	16 52	14 50	12 52
γ Draconis	2.4	11 13	9 11	7 21	5 19	3 21	1 19	23 17	21 15	19 13	17 15	15 13	13 15
ε Sagittarii	2.0	11 37	9 35	7 45	5 43	3 45	1 43	23 41	21 39	19 37	17 40	15 38	13 40
α Lyræ	0.1	11 52	9 50	8 0	5 58	4 0	1 58	0 0 / 23 56	21 55	19 53	17 55	15 53	13 55

MERIDIAN TRANSIT OF STARS, 1925.

CORRECTIONS TO BE APPLIED TO THE CIVIL TIME OF TRANSIT ON THE FIRST DAY OF THE MONTH, TO FIND THE CIVIL TIME OF TRANSIT ON ANY OTHER DAY OF THE MONTH.

Day of Month.	Correction.	Day of Month.	Correction.	Day of Month.	Correction.
	h m		h m		h m
1	0 0	11	−0 39	21	−1 19
2	−0 4	12	0 43	22	1 23
3	0 8	13	0 47	23	1 27
4	0 12	14	0 51	24	1 30
5	0 16	15	0 55	25	1 34
6	−0 20	16	−0 59	26	−1 38
7	0 24	17	1 3	27	1 42
8	0 28	18	1 7	28	1 46
9	0 31	19	1 11	29	1 50
10	0 35	20	1 15	30	1 54
11	−0 39	21	−1 19	31	−1 58

NOTE.—If the quantity taken from this table is greater than the civil time of transit on the first of the month, increase that time by $23^h\ 56^m$ and then apply the correction taken from this table.

TABLE I.

FOR FINDING THE LATITUDE BY AN OBSERVED ALTITUDE OF POLARIS, 1925.

Reduce the observed altitude of Polaris to the true altitude.

Reduce the recorded time of observation to the local sidereal time.

With this sidereal time take out the correction from the table below, and add it to or subtract it from the true altitude, according to its sign. The result is the approximate latitude of the place.

Example.—June 10, 1925, at about $22^h\ 30^m$ ($10^h\ 30^m$ P.M.), local civil time, when the Greenwich civil time is June 11, $3^h\ 36^m\ 30^s$, in longitude 74° west of Greenwich, suppose the true altitude of Polaris to be 39° 46′, required the latitude of the place.

	h	m	s
Greenwich civil time	3	36	30
Greenwich sidereal time of 0^h Greenwich civil time, June 11, page 2	17	15	16
Reduction from page 2 for Greenwich civil time	+	0	36
Greenwich sidereal time	20	52	22
Longitude, 74° =	4	56	0
Local sidereal time	15	56	22
		°	′
True altitude		39	46
Correction from table below	+	0	54
Latitude	+	40	40

Local S. T.	0^h		1^h		2^h		3^h		4^h		5^h	
m	° ′		° ′		° ′		° ′		° ′		° ′	
0	−1 0.0	12	−1 4.9	4	−1 5.3	4	−1 1.1	11	−0 52.6	17	−0 40.6	23
10	1 1.2	10	1 5.3	2	1 4.9	5	1 10.0	13	0 50.9	19	0 38.3	24
20	1 2.2	8	1 5.5	1	1 4.4	7	0 58.7	13	0 49.0	19	0 35.9	24
30	−1 3.0	8	−1 5.6	0	−1 3.7	7	−0 57.4	15	−0 47.1	21	−0 33.5	25
40	1 3.8	6	1 5.6	1	1 3.0	9	0 55.9	16	0 45.0	21	0 31.0	26
50	1 4.4	5	1 5.5	2	1 2.1	10	0 54.3	17	0 42.9	23	0 28.4	26
60	−1 4.9		−1 5.3		−1 1.1		−0 52.6		−0 40.6		−0 25.8	

Local S. T.	6^h		7^h		8^h		9^h		10^h		11^h	
m	° ′		° ′		° ′		° ′		° ′		° ′	
0	−0 25.8	27	−0 9.3	29	+0 7.9	28	+0 24.5	26	+0 39.3	23	+0 51.5	17
10	0 23.1	27	0 6.4	29	0 10.7	28	0 27.1	25	0 41.6	21	0 53.2	17
20	0 20.4	27	0 3.5	28	0 13.5	28	0 29.6	26	0 43.7	21	0 54.9	15
30	−0 17.7	28	−0 0.7	29	+0 16.3	28	+0 32.2	24	+0 45.8	20	+0 56.4	14
40	0 14.9	28	+0 2.2	28	0 19.1	27	0 34.6	24	0 47.8	19	0 57.8	13
50	0 12.1	28	0 5.0	29	0 21.8	27	0 37.0	23	0 49.7	18	0 59.1	11
60	−0 9.3		+0 7.9		+0 24.5		+0 39.3		+0 51.5		+1 0.2	

Local S. T.	12^h		13^h		14^h		15^h		16^h		17^h	
m	° ′		° ′		° ′		° ′		° ′		° ′	
0	+1 0.2	11	+1 4.9	4	+1 5.3	4	+1 1.3	11	+0 53.1	17	+0 41.4	22
10	1 1.3	10	1 5.3	2	1 4.9	5	1 0.2	12	0 51.4	18	0 39.2	24
20	1 2.3	8	1 5.5	1	1 4.4	6	0 59.0	13	0 49.6	19	0 36.8	24
30	+1 3.1	8	+1 5.6	0	+1 3.8	7	+0 57.7	15	+0 47.7	20	+0 34.4	24
40	1 3.9	6	1 5.6	1	1 3.1	9	0 56.2	15	0 45.7	21	0 32.0	26
50	1 4.5	4	1 5.5	2	1 2.2	9	0 54.7	16	0 43.6	22	0 29.4	25
60	+1 4.9		+1 5.3		+1 1.3		+0 53.1		+0 41.4		+0 26.9	

Local S. T.	18^h		19^h		20^h		21^h		22^h		23^h	
m	° ′		° ′		° ′		° ′		° ′		° ′	
0	+0 26.9	26	+0 10.5	29	−0 6.6	29	−0 23.4	26	−0 38.5	23	−0 51.0	18
10	0 24.3	27	0 7.6	28	0 9.5	28	0 26.0	26	0 40.8	22	0 52.8	17
20	0 21.6	28	0 4.8	29	0 12.3	28	0 28.6	26	0 43.0	22	0 54.5	15
30	+0 18.8	27	+0 1.9	28	−0 15.1	28	−0 31.2	25	−0 45.2	20	−0 56.0	15
40	0 16.1	28	−0 0.9	29	0 17.9	28	0 33.7	24	0 47.2	20	0 57.5	13
50	0 13.3	28	0 3.8	28	0 20.7	27	0 36.1	24	0 49.2	18	0 58.8	12
60	+0 10.5		−0 6.6		−0 23.4		−0 38.5		−0 51.0		−1 0.0	